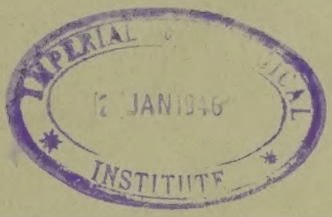
Vol. 11 No. 4

April, 1945

THE BOTANICAL REVIEW

Interpreting Botanical Progress

Plant Growth Relations on Saline and Alkali Soils.
O. C. MAGISTAD 181



PROPOSED FUTURE
CONTENTS ON REAR COVER

Published Monthly except August and September at
North Queen St. and McGovern Ave., Lancaster, Pa.

Entered as second-class mail matter February 4, 1935, at the Post Office at Lancaster, Pennsylvania, under the Act of March 3, 1879.

THE BOTANICAL REVIEW

Founded in 1935 by
H. A. GLEASON AND E. H. FULLING
Managed, edited and published at
The New York Botanical Garden
by
E. H. FULLING

Advisory Editors

PROF. S. A. CAIN, ecology
PROF. R. W. CHANEY, paleobotany
PROF. A. J. EAMES, morphology
DR. A. F. HILL, economic botany
PROF. JOHN S. KARLING, mycology
PROF. M. M. RHOADES, genetics
PROF. GILBERT SMITH, phycology
PROF. N. E. STEVENS, pathology
PROF. S. F. TRELEASE, physiology
PROF. CONWAY ZIRKLE, cytology

THE BOTANICAL REVIEW is published monthly except August and September. Subscription rate for the United States is $4.00 per year; for Canada and other foreign countries $4.25; single copies, 50¢. All subscriptions are payable in advance at par in Lancaster, Pa., or New York. Checks should be made payable to THE BOTANICAL REVIEW.

Manuscripts are prepared by contributing authors only upon invitation and on the suggestion or with the approval of the advisory editor in whose field the subject lies. Unsolicited manuscripts will not be considered. The editor, nevertheless, welcomes suggestions of topics which might properly be reviewed.

Missing numbers can not be supplied unless notice is received within two months after appearance of issues concerned.

All correspondence should be addressed to THE BOTANICAL REVIEW, at N. Queen St. and McGovern Ave., Lancaster, Pa., or Fordham P. O., New York, N. Y.

THE BOTANICAL REVIEW

VOL. XI APRIL, 1945 No. 4

PLANT GROWTH RELATIONS ON SALINE AND ALKALI SOILS

O. C. MAGISTAD
U. S. Regional Salinity Laboratory, Riverside, Cal.

FOREWORD

Serious study of saline and alkali soils and their relation to plant growth was begun by Hilgard (125) before 1886 and later summarized in 1900 (126) and 1906 (127). It received a mighty impetus with the work of Gedroix (78, 79, 80, 81, 82, 83), de Sigmond (297, 298, 299, 300, 301, 302, 303, 304, 305, 306), Kelley (164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179) and Hissink (128, 129, 130, 131, 132, 133, 134, 135) who all demonstrated that alkali soils differ from normal soils in containing abnormal quantities of replaceable sodium. Harris (99), in his book in 1920, reviewed the subject of alkali soils, but this was prior to a general knowledge of base exchange in soils and many recent advances in plant physiology. Saline and alkali soils usually occur in arid regions where rainfall and leaching are insufficient to carry away the soluble salts.

On saline soils evidence indicates that plants are reduced in growth mainly because of the increased osmotic pressure of the substrate, while on alkali soils, usually with high pH values and oftentimes in the presence of sodium carbonate, plant growth is also reduced because of poor soil permeability to water, lack of oxygen in the soil air, malnutrition, chlorosis, and even corrosive action. These subjects will be reviewed later, but they indicate the need for a brief review of the various types of salty soils and their nature.

CLASSIFICATION AND COMPOSITION OF SALINE AND ALKALI SOILS

Formation

Clear-cut terminology and classification of salty soils has not yet been obtained. The processes which lead to formation of salty soils can be summarized as follows (11, 37, 80, 82, 166, 167, 187, 301):

a. Salts usually accumulate in soils because neither the surface nor the ground waters drain away. With evaporation directly or by transpiration the salt concentration is increased. Sodium salts may predominate at the outset; however, with further concentration, calcium, because of the limited solubility of calcium carbonate and calcium sulfate, is usually precipitated out of solution with a further increase in the relative proportion of sodium. This process of salt accumulation is called "salinization" (167, 301).

b. An equilibrium exists between the distribution of bases in the soil solution and on the soil colloids. With higher actual and relative quantities of sodium present in the soil solution greater quantities of sodium are absorbed by the soil colloids with a corresponding release of other cations previously absorbed. This process, in which the percentage of sodium on the exchange complex is increased, is called "alkalization" (301).

c. With subsequent leaching and removal of soluble salts the soil colloids disperse because the coagulating effect of the electrolyte is removed. The process of salt removal is called "desalinization" (167, 301).

d. With desalinization (301) new equilibria between sodium in the soil complex and in the soil solution are set up, with loss of sodium from the complex. If the soil is calcareous or gypsiferous so that relatively large quantities of calcium are always present in the soil solution, calcium will exchange for the sodium removed from the soil complex, forming again, from a chemical standpoint, a normal soil. More often there is little calcium present in the soil solution, and sodium is hydrolyzed from the complex with the formation of small amounts of hydrogen clay and sodium hydroxide. The sodium hydroxide reacts with carbon dioxide from the soil air to produce sodium carbonate. The pH value of the soil usually rises to above 8.5. This process of sodium removal with hydrogen exchange is called "degradation" (301) and "solotization" (167, 301). With prolonged leaching the sodium carbonate is removed and hydrogen exchange may go so far that the pH values of the surface soil may fall below 6.0.

e. If a supply of soluble calcium is made available to a degraded soil, this calcium will replace the exchangeable hydrogen and again form a soil normal with respect to its exchangeable bases. The calcium is usually supplied by addition of agricultural lime (calcium carbonate). This process is called "regrading" a soil.

Classification

On the basis of the chemical changes involved de Sigmond (301, 304) classifies salty soils in the various stages of formation into:

1. "Saline soils" which contain over 0.1% salt and less than 12% of the exchangeable bases K + Na. This corresponds to phase (*a*) above; to Gedroix's term "Solonchak" (82) and roughly to Hilgard's term "white alkali". pH values of the soil at normal field moisture contents usually are below 8.5.

2. "Saline alkali soils" which contain over 0.1% salt and over 12% replaceable K + Na. This corresponds to phase (*b*) above. The value of 12% K + Na is taken provisionally because at about this range soil dispersion is serious, and the soil has a markedly lower permeability if leached. Soil pH values may slightly exceed 8.5.

3. "Slightly saline alkali soils" contain over 12% replaceable K + Na, and slightly over 0.1% salt. This type corresponds to (*c*) above and is produced by desalinization. These soils also often contain sodium carbonate. pH values usually range between 8.5 and 10.0.

4. "Degraded alkali soils" contain less than 0.1% salt and appreciable quantities of replaceable hydrogen. Soil pH values in the surface horizons may be below 6.0, but are usually between 6.5 and 8.0.

5. De Sigmond has also included a fifth class called "regraded alkali soil" containing a normal quantity of replaceable Ca + Mg and produced by process *e* above. Since this type of soil is again normal, it is no longer an alkali soil and should not be included as an alkali soil.

Kowda (187) has divided alkali soils into five classes based on salt content, carbonate content, presence of gypsum and location of the lime layer, while Antipov-Karataev (11) also includes organic matter.

To illustrate the difference in exchangeable bases between normal, saline and alkali soils, the following table has been prepared from data as indicated:

		Exchangeable bases Relative per cent				*References*
		Ca	Mg	K	Na	
Normal soil						
California soils	av. 7	63	25	4	8	169
Russian soils	av. 2	82	11	7	0	169
Holland soils	av. 26	79	13	2	6	130, 169

Saline soils					
California soils av. 9	67	26	3	4	170 (table 4)
Alkali soils (Western U. S.)					
Intermediate av. 5	43	21	10	26	170 (table 3)
Extreme av. 14	4	8	16	72	170 (table 2)

It will be noted that normal and saline California soils have approximately the same distribution of exchangeable bases. The saline soils differ from the normal in containing 0.2% soluble salts. Many authors take 0.1% as the threshold of saline soils, particularly if chlorides predominate.

Most other writers (82, 90, 127, 166, 180, 323, 340) have failed to break the soils down into as many classes as has de Sigmond. The Division of Soil Survey (47) recognizes saline soils and alkali soils approximately as defined above. Kelley (167) has objected to classifications such as that of de Sigmond's on the ground that one class merges into another. He has used Hilgard's nomenclature in which alkali is used in a generic sense to include all classes (1 to 4 inclusive) above. Hilgard (127) differentiated between "white alkali" and "black alkali". His white alkali would probably include classes 1 and 2 above, and black alkali classes 3 and 4. Gedroix (82) used the terms "Solonchak" to designate a saline soil without structure and "Solonetz" "a type of soil in which base exchange silicates contain appreciable quantities of replaceable alkali bases, chiefly sodium" (82). The degraded alkali soil is called "Solodi" by Gedroix on the basis of chemical characteristics. Antipov-Karataev (11), in a review of Russian work, classified solonetz soils as follows:

a. "Tschernozemartige Solontzi"—containing over 30% replaceable Na in the exchange complex of the illuvial horizon.

b. "Humus poor Solontzi"—containing over 20% replaceable Na.

c. "Solonetz-like soils"—not true Solonetz soils but which have many of their properties:

1. "Tschernozemartige"—3–20% replaceable Na.
2. "Chestnut colored"—5–20% replaceable Na.

Other Russian investigators were more concerned with soil classification and mapping from visual criteria (89, 340). Vilensky used the term "Solonchak" to denote a saline soil without defined structure, and "Solonetz" a salt soil with structure (178, 341). In the English language the meaning of the terms "saline" and "alkali" is gradually being restricted, and the author here uses "salty" in a

generic sense to include all soils (1 to 4 inclusive above); this is not a new use (301, 339). The Russians also use the root "solon" in this sense. De Sigmond has used the generic terms "salty" (301), "sodium" (304) and the Hungarian term "Szik" to include both saline and alkali soils. The terms "Reh" and "Usar" (India) (69, 125, 307) and "Brak" (South Africa) (329, 358) are also used in this manner, although (323) states that "reh" is a saline soil, "bara" an alkali soil and "bari" a partially alkalized soil. The Indian writers (323) indicate that alkali soils have a pH over 8.5 and the effect of high replaceable sodium exceeds the effect of soluble salts. Trietz (328) has found vegetation a good index to the nature of alkali soils.

In this review saline soils will be defined as class 1 above, while alkali soils will include those containing over 12% replaceable alkali bases.

Base Exchange Relations

It is now well established (9, 95, 118, 173, 174, 175) that the base exchange materials in a mineral soil are crystalline in nature. The best recent reviews of this subject are by Grim (95), Hendricks (118), Kelley (168) and Scheffer and Schachtschabel (286). These soil minerals are of three main types: montmorillonite, hydrous mica (illite) and Kaolinite. The first has a marked expanding lattice and a base exchange capacity of 60–100 milligram equivalents per 100 grams. The illite or hydrous mica group has a structure similar to montmorillonite but does not expand. It has a capacity of 20–40 m.e./100 grams. Kaolinite does not expand with varying water content and has a capacity of 3–15 m.e./100 grams (95). The spaces between the lattices of these crystals are large enough to permit easy entrance of the common soil bases in base exchange for exchange purposes (95). The size of these soil crystals is usually less than 5 μ in diameter. While it is well established that organic matter in soils has a high base exchange capacity (3, 83, 132, 222, 223, 224, 239, 241, 249, 251, 286, 349), little is known of the mechanism responsible. Base exchange capacities of organic matter as great as 431 m.e./100 grams are reported (223).

There are two principal methods of determining the nature of the base exchange crystals in a soil: by means of X-ray diffraction (121, 173, 177) and by differential thermal analysis (120, 177). Kelley, Dore, and Page (174) have reported that saline (white alkali) soils

of the West contain all three types of soil minerals, while the alkali soils (black alkali) contained chiefly mica-like minerals. The methods used by them have been criticized, as they did not initially saturate the soils with calcium or control the hydration. Aldrich, *et al.* (8) indicate that this is necessary because with sodium as the adsorbed base and lack of moisture control the diffraction lines of montmorillonite are almost identical with those of hydrous mica and the mineral may easily be mistaken for hydrous mica.

The soil minerals present in alkali soils are believed to be largely montmorillonite and hydrous mica (9, 119, 292).

Composition of Salts in Saline Soils

De Sigmond (304) classifies the salts in saline soils on the basis of the nature of the anions present into: soils with (*a*) sulfates, (*b*) chlorides, (*c*) sulfates plus chlorides, (*d*) sulfates plus carbonates, (*e*) chlorides plus carbonates, (*f*) chlorides plus sulfates plus carbonates, and (*g*) soda soils. The farmers of India also have specific names for the various salt types (69). It appears doubtful that sodium carbonate can be present in any quantity in soil solutions, and the soil remain a saline soil (below 12% K + Na). It would appear that if soluble carbonates are present in the soil it is a saline alkali or alkali soil. Classification of saline soils on the basis of the cations present rather than the anions would have many advantages, especially in base exchange equilibria studies.

Kelley and Brown (170) list analyses of nine saline soils (those containing less than 10% replaceable sodium). The total soluble salt content ranges from about 2,000 p.p.m. to about 60,000 p.p.m. Sodium is the predominant cation in most cases, and chlorides or sulfates are the predominant anions. No soluble carbonates are present which could be titrated with phenolphthalein as an indicator. These analyses are typical for saline soils (37, 48, 127, 203, 213, 291, 313).

In some localities sodium may not be the predominating cation; thus analyses are reported where calcium exceeds sodium and where magnesium exceeds sodium (48, p. 73).

Chlorides and sulfates are the predominant anions in saline soils. In certain regions, *e.g.*, the Pecos River Valley of New Mexico and Texas (291), the Billings area of Montana (48, p. 109), the San Luis Valley of Colorado (48, p. 117), Alberta, Canada (256), and

parts of Hungary (302), sulfates markedly predominate. Occasionally nitrates may be present in large quantities (10, 190). One analysis is listed where 5,000 p.p.m. of nitrate were present in the soil and far exceeded the quantities of other anions (170). Humid soils may sometimes contain excessive nitrates (42).

Chemical Nature of Alkali Soils

In normal soils calcium plus magnesium constitutes 90% to 95% or more of the replaceable bases (11, 139, 169). The predominant characteristic of an alkali soil is that the alkali bases, sodium and potassium, constitute more than 12% of the total replaceable bases, when calculated on an equivalent basis. De Sigmond (301, 305) is probably the only author who has specifically mentioned 12%, but most authors on the subject would put the value not much above 20% (11). De Sigmond arrives at this value because when soils contain more alkali replaceable bases, they become dispersed when leached (94). An inspection of the data from (266) indicates that pH values rise above 8.5 when the replaceable sodium percentage exceeds 14. Fireman and Magistad (62) have unpublished work which also indicates a decided decrease in permeability of soils when replaceable sodium exceeds 10–15% of the sum of the replaceable bases. The sum of replaceable bases in milliequivalents per hundred grams is commonly designated by the letter S (132).

While some (265, 301) include replaceable K with replaceable Na, the amount of replaceable potassium found in soils is usually only 1% to 5% and is ignored. Occasionally the value may be great. Thus Kelley (170) lists analyses where K constitutes as much as 40%, 11% (324), and 30% (189) of total capacity.

Magnesium-saturated soils are said to have some of the physical properties of sodium-saturated soils (248, 312). Replaceable magnesium constitutes a large portion of the base exchange capacity in some soils of solonetz structure (60, 167, 180, 189, 248, 280, 281, 320), but whether it is the cause of such structure or only remains after sodium salts have been removed, is unknown.

Definite equilibria exist between the bases in solution and the replaceable bases on the soil minerals (14), which has been represented by absorption isotherms (151, 357) but more accurately by mass action equations (182, 259, 335), particularly that of Gapon (12, 70, 211).

Analysis of Soils for Soluble Salts and Replaceable Bases

Soluble salts can be readily determined with fair accuracy in soils which do not contain calcium carbonate, gypsum or much replaceable sodium (95). Where gypsum is present the amount of calcium and sulfate ions found will depend upon the amount of water used to remove the salts (95). In the presence of considerable replaceable sodium the equilibrium between calcium and sodium in the solution and on the colloid varies with the water content; hence here, too, unless one obtains the soil solution at normal moisture contents, errors are introduced (29, 78, 83, 95). In the presence of replaceable sodium and calcium carbonate, addition of water shifts the equilibrium so that replaceable Na is released and sodium carbonate formed (29, 57, 78). For this reason many of the older analyses in the literature on the quantities of sodium carbonate in soils are very questionable. Sodium carbonate does exist in many alkali soils, but in alkali soils containing calcium carbonate or gypsum the amounts reported are usually too great (243). In the same manner difficulties arise in the determination of replaceable bases. One cannot leach out the soluble salts and expect to retain the replaceable bases unaltered (72, 129). In the presence of calcium carbonate and gypsum the replacing reaction does not go entirely to completion, and, furthermore, when the soil is leached with a reagent to remove the replaceable cations, this solution contains in addition some dissolved calcium from the calcium carbonate, gypsum and soil minerals. More satisfactory methods for determination of replaceable bases in the presence of gypsum are needed.

The replaceable sodium content of alkali soils may nearly reach 100% of the total capacity (170, 265, 268, 362).

PLANT RELATIONS TO SALINE SOILS

Plant relations to saline and to alkali soils will be discussed separately. The present section will be limited to saline soils containing the common salts, *i.e.*, combinations of the ions Ca, Mg, Na, Cl, SO_4, HCO_3 and NO_3. (Alkali soils contain more replaceable sodium than saline soils, often contain sodium carbonate, and usually have pH values above 8.5.)

Western soils are usually fertile mainly because they have undergone little leaching. Most western soils require additional nitrogen, and some, especially in the Northwest, boron and sulphur. As a

rule, therefore, there is little deficiency of phosphorus, potassium, calcium or magnesium, although phosphorus is becoming increasingly deficient. On the other hand, in saline soils there is usually an excess of calcium, magnesium and occasionally of potash, nitrates and boron (207). It seems best to review the literature on plant relations in saline soils on a causative basis rather than chronologically. Many of the pieces of work can now be interpreted in the light of present knowledge and new over-all conclusions reached.

The older investigators searched for toxic substances or toxic concentrations, but more recent work indicates that with increasing salt content growth is usually merely inhibited.

Growth Reduction Rather Than Toxicity

Eaton (54, 56) was one of the first American writers to point out that when grown in a saline solution, plants are merely reduced in growth without any marked change in outward appearances. He stressed the fact that there is no toxic limit short of which healthy plants are produced and which if exceeded, causes death. This view has been substantiated by more recent work (15, 46, 49, 74, 76, 112, 114, 209, 210, 247), and re-examination of older work points to the same conclusion (161, 216, 221, 331, 332). A large number of investigators have reported reduced growth at concentrations somewhat in excess of two atmospheres osmotic pressure when compared to lower concentrations (15, 17, 46, 49, 56, 65, 73, 74, 75, 77, 91, 110, 112, 114, 116, 136, 195, 209, 216, 221, 240, 247, 252, 294, 311, 318, 319, 327, 331, 338, 345, 347, 356), and this growth depression is roughly proportional to the increase in osmotic pressure. In some instances approximate osmotic values have been calculated by the author for the above experiments. A number of writers believe that it is the individual action of certain ions in salt solutions which is the cause of reduced growth rather than the osmotic effect. This is particularly true of certain very toxic or corrosive ions like CO_3^{--}. The fact that approximately equal growth reductions are obtained at the same osmotic level, when produced by the common salts of saline regions, lead most people to accept the osmotic theory. This will be discussed further throughout the paper.

The optimum concentration for growth varies with the crop and experimental conditions. Where aeration is provided for, and there is a plentiful supply of nutrients obtained by frequent changes of

solution, maximum growth is often obtained at concentrations below one atmosphere (31, 75, 114, 136, 236, 247, 347, 348).

Osmotic Effects and Water Relations

The plant absorbs water because the osmotic pressure of the root cells is greater than that of the soil solution, according to Maximov (219) and others (321). The turgor pressure of the cell wall modifies the osmotic pressure of the cell contents so that the net effect governing water intake is best described by a term such as "diffusion pressure deficit (237). In this paper osmotic pressure of plant parts has this overall meaning. If the concentration of the soil solution is increased, the osmotic pressure gradient is decreased and water absorption goes on at a slower rate. The plant, however, can in part accommodate itself to such a condition by increasing the osmotic pressure of the cell sap (52, 54, 55, 56, 112, 146, 219). Salt marsh plants and desert plants in general have saps of high osmotic pressure, and J. Arthur Harris and co-workers carried on much work to correlate the plant sap concentration with that of the substrate (50, 63, 100, 101, 102, 103, 105, 106, 107, 219 p. 276, 351). In a number of instances cell sap concentrations, as determined by the freezing point method, were found to exceed 40 atmospheres (101, 146), although sap of agricultural plants usually had an osmotic pressure ranging from 10 to 20 atmospheres (56, 146).

The osmotic pressures of soil solutions from saline soils vary with the amount of salts present, the water content, the nature of the salts and the nature of the soil. In any particular soil the soil solution is most concentrated, as far as the plant is concerned, when the moisture content is reduced to the wilting percentage (28). Magistad and Reitemeier (213) reported the osmotic pressures of such soil solutions to be in the neighborhood of one to two atmospheres for normal productive soils and as high as 200 atmospheres or more for barren saline soils. Poor crop growth was obtained with soils having osmotic pressure of 10 atmospheres and none at 47 atmospheres. The soil moisture content may never be depleted to the wilting percentage and at maximum soil moisture content (*i.e.*, field capacity) the osmotic pressure of the soil solution is only about half that at the wilting range. Vikulina (338) reported similar results.

High osmotic pressures of the soil solution are not restricted to western saline soils. Heavy applications of soluble fertilizers often

increase the salt concentration of the soil solution to a degree injurious to plant growth, especially on sandy soils. Thus fertilizer applications of 1,200 pounds per acre on Norfolk sandy loam increased the osmotic pressure of the displaced soil solution to about 14 atmospheres (359). Fertilizer applications at rates as great as this are occasionally made.

To investigate the effect of osmotic pressure of substrate on water absorption by plants, Eaton (55) placed a part of a root system in a dilute solution and part in concentrated solution and showed that water absorption was mainly from the dilute solution. Similar experiments with approach grafted tomatoes (199) resulted in decreased water intake from the concentrated solutions as well as from solutions having high osmotic pressures as a result of additions of salts or sugars. The most direct measurements are those which attached potometers to *Allium sepa* and corn roots, respectively, and measured water intake (113, 279). For non-conditioned intact plants Hayward and Spurr obtained the following rates of water intake at 10 cm. from the root tip:

	Water intake mm.³/mm.²/hr.
control − .8 atm.	0.249
control + 2 atm.	0.075
control + 4 atm.	0.030

The rate of water absorption is of course also related to climate conditions and the rate of transpiration. As Maximov (219) has pointed out, the shoots of desert plants and halophytes are adapted to decrease the rate of transpiration yet maintain sufficient area to take in the necessary carbon dioxide and provide for photosynthesis.

One group of men (16, 198, 311*a*) in their work and reviews indicate that normal vegetative growth and succulence is associated with tissues which have a high colloid and moisture content and a plentiful supply of nitrogen. If the moisture content drops, the soluble salts within the cell may exceed critical values and be partially or wholly precipitated or salted out. This is apt to happen during periods when water demand is high, as in flowering or during periods of hot dry weather. Older leaves can not recover once their colloids have been partially dehydrated, and thereafter they will have a lower water content and may die. Thus Bakhuyzen (16) believes that annuals die after flowering because they have lost so much water at the time of flowering that the plant can not recover.

A somewhat different view is presented by Iljin (146) and Maximov (219, 220). They postulate that with decrease in water content the cell contents and protoplasm shrink away from the cell wall. Once there is a separation at this point, water can not be conducted to the protoplasm and permanent wilting ensues. Some plants like sunflower, according to Maximov (219, p. 313), can lose as much as 25% of water and recover, while some shade plants can not recover if they lose 2% to 3% of water. This difference in behavior he ascribes to the elasticity of cell walls in the case of plants like sunflowers which permit the cell wall to follow the contracting protoplasm.

Caldwell (38), working with four plant species, noted large decreases in per cent moisture of leaves of plants when grown in nutrient solutions of several atmospheres. Similar data were obtained for barley (73) and flax in calcium chloride solutions, but not in substrates with sodium chloride and sodium sulfate (114). According to the theories given above, the plant in saline solutions will first have a water loss which is not recovered in the older leaves. Hence these leaves thereafter will have a lower moisture content. Newer leaves and parts may have a relatively high water content.

Soluble organic materials, especially sugars, also contribute to the osmotic pressure of plant cells. Decrease in water content in some way increases enzyme activity and hydrolysis of carbohydrates to simple sugars.

Henchel and Kolotova (117) classify halophytes into three groups based on the mechanism for salt tolerance, *i.e.,* those with great tolerance or endurance to the increased salt content within the cells, those that can excrete or eliminate excess salt, and those that have a low permeability of protoplasm to salts. Under the first category would be included those plants which can tolerate high osmotic pressures in the cell sap; some examples are given in which these pressures exceed 40 atmospheres (101, 219, p. 19). The other two categories will be discussed under the section *Soils of Low Permeability.*

The view that salt tolerance is largely a matter of reduced water uptake has been retarded by the fact that many have interpreted these same experimental data on the basis of antagonism, and by the wide-spread belief that plants do not suffer from lack of water at soil moisture contents above the wilting coefficient. Several investigators have plotted daily growth or transpiration against time

and have noted no perceptible decrease in this rate before the permanent wilting percentage was reached (122, 123, 336, 337). From this they concluded that water is equally available to the plant from field capacity to the neighborhood of the permanent wilting percentage. Since these experiments were usually conducted in soils of low salt content, investigators ascribed reduced growth rates in the presence of salt to the salt *per se,* and considered that water availability was not involved to any appreciable extent.

The work of Briggs and Shantz (32, 33) and of more recent authors has indicated that all plants wilt at about the same moisture content in any soil, or in terms of tension units, at about 15 to 20 atmospheres. Since less than 10 atmospheres of added salt will in many instances cause death of plants in sand cultures, this was considered additional evidence that the plants did not die for lack of water but because of some action of the salt. With advances in the field of soil moisture relationship the stage has recently been set for clarification of these views.

Day (45) and later others (21, 58) postulated from thermodynamic reasons that the moisture potential of a soil is equal to the sum of the pressure potential plus the osmotic potential. That is, the free energy of the water in the soil, and hence its relative availability to plants, is proportional to the forces holding the water to the soil plus the osmotic forces of the dissolved salts, and to be additive, they must both be expressed in similar units, such as ergs per gram of water. Physicists have used the unit ergs per gram of water when measuring potentials. Other soil moisture and plant investigators have not been as precise and have discussed the forces on an area basis rather than a mass basis. Thus much of the data in the literature has been expressed in atmospheres, or tensions per unit area, and these terms are more familiar to plant men. Under standard conditions one atmosphere = a tension corresponding to a pressure head of 1,029 cm. of water and corresponds to a potential of 1.01×10^6 ergs per gram. On this basis the wilting range of soils has been found to be about 15 atmospheres (277, 321) and 10 to 23 atmospheres (58). Thus plants will be unable to obtain water rapidly enough to maintain life when the moisture stress reaches about 15 atmospheres, whether because of a drying soil, or the presence of salts, or both. That this conception has considerable support is evidenced by the data (277) of the best correlation between

moisture potential and wilting range when osmotic potentials were included, and by others (15, 58, 213). Webster and Viswanath (356), working in Iraq, state that plants wilt more quickly in a salty soil than in the same soil with the salt removed. They also suggest that a soil is too saline for growth of wheat and sorghum when the osmotic pressure of the soil solution to a depth of six feet, determined at the minimum capillary capacity, exceeds six atmospheres. According to this concept, plants have greater difficulty in obtaining water at moisture contents nearing the permanent wilting percentage than at field capacity (188, 345), but the differences are not readily demonstrable. Wadleigh and Ayers (345) have recently presented additional evidence and have reviewed this subject.

Many workers have noted the relationship between drought-resistant plants and salt-tolerant plants, and these two branches of study were at one time united under Alkali and Drought Investigation in the Bureau of Plant Industry. There are of course many distinctions between the two; thus some plants are drought-resistant because of their deep root systems but may be quite sensitive to salt. Nevertheless, a consideration of water requirements and the availability of water in terms of free energy or some similar concept will do much to clarify the similarities and differences between salt tolerance and drought tolerance.

If the salt had no action beyond decreasing water availability we would expect plants to wilt at a certain water tension in a salt-free soil of about 15,000 cm. water per sq. cm. or approximately 15 atmospheres. Here the osmotic potential would be close to zero. In a sand culture solution the pressure potential would be nearly zero (the water is not held by the sand with any appreciable force) and the moisture stress should be approximately equal to the osmotic potential. We would then expect plants to die in a salt solution of 15 atmospheres osmotic pressure. It is too early to tell if this relationship holds. Almost certainly there are some salt effects in addition to water retention effects. If the relationship did hold, we would expect to find some plants having wilting coefficients of 20 atmospheres or more, and others probably below 10 atmospheres. This is not in accord with the customary interpretation of wilting coefficients. Yet an examination of the data of Briggs and Shantz on relative wilting coefficients (32) shows *Colocasia,* hydrophytes and xerophytes had values substantially greater than the others;

the difference undoubtedly exceeded probable error. Thus even the data of Briggs and Shantz would indicate that possibly all plants do not wilt at the same moisture tension. Part of this may be caused by lack of a well branched root system. Now that we know the nature of the force-moisture content curve (278, 285, 345) it is clear that differences in moisture content between 10 and 20 atmospheres are difficult to determine by soil sampling because of the steepness of the curve in this region and the magnitude of the sampling error.

It should be borne in mind that the plant is not static and that plants from the same original group will have higher internal sap concentrations when grown in salt solutions than when grown in more dilute solutions (56, 146, 311). Thus these plants tend to become adapted to their surroundings in such a way as to maintain an osmotic gradient favorable to water intake. The same is true of plants conditioned to cold.

Several authors have worked with bacteria rather than larger plants and have noted the relationship between osmotic pressure of substrate and growth depression (17, 93).

The electrical conductivity of soil solutions or substrates also correlates well with osmotic pressures of such substrates (43, 51, 209, 236), and in field practice it may be more convenient to determine electrical conductance rather than osmotic pressures as an index of the amount of salt present and of the unavailability of water to plants.

Salt Absorption and Accumulation

The older literature on permeability, antagonism and salt absorption is far from clarifying. Fortunately this subject was recently discussed and reviewed in 1940 by a group of biologists in a symposium at Cold Spring Harbor (262), and with special reference to agricultural plants (138), by Hoagland in his book (139) and in The Botanical Review (137). Many of the studies on salt accumulation have been made on large-celled marine forms, on potato discs, and some on excised plant roots, and on many points the results of researches on such varied materials are in agreement. Only the main points will be reviewed here with particular emphasis on plant relations in saline soils.

The concentration of ions, as a whole or singly, is usually greater in the cell sap than in the soil solution. Absorption is therefore against a gradient which may be very great. Thus Hoagland and

Davis (142), working with *Nitella,* showed that the concentration of K in the sap reached over 50 milliequivalents per liter when grown in pond water of 0.051 m.e. K per liter or absorption took place against a concentration gradient of 100. Similar gradients for other ions were Cl—100×, SO_4—30×, Ca—15×, Mg—6×, and Na—65×. The total concentration of sap in these *Nitella* cells reached the very high value of 173.5 m.e. per liter. Similar results have been obtained with *Chara* (40). Excised barley roots can accumulate K to a level of 20 to 50 m.e. per liter in the cell sap under proper conditions (141). Similar high cell sap concentrations have been found in tomatoes (112) and for various other crops (56).

Jacobs (150) has pointed out that accumulation is proportional not to the concentration of that ion in the external medium but to the differences in concentration inside and outside the cell. Thus a cell which is depleted or in a low state of supply as regards a particular ion will absorb that ion more readily. From the standpoint of gradients a cell can more easily absorb the essential ions from saline solutions than non-saline because the gradient is less.

Oxygen Supply

Work is performed in transporting ions against a concentration gradient, and the energy for this comes from oxidation of carbohydrates. The amount of oxygen required varies with the type of tissue (40, 258). While saline soils are usually "open" compared to alkali soils, they may often have low contents of oxygen in the soil air and thus restrict root activity. Of particular interest are recent papers (22, 23, 24, 25) which suggest that oxygen content of soil air is related to root activity of apple trees about as follows:

Per cent oxygen	
0.1– 3	roots merely subsist
5–10	root tips grow
10–12	water absorption proceeds
over 12	new roots form

Recent other work (342) has substantiated the correlation between poor cacao yields and low oxygen contents in the soil air. Magistad (in unreported work) observed yellowing of alfalfa in August when soil moisture tensions remained less than 100 cm. water for only 10 days, but during December and January, when temperatures were low and growth was slow, the alfalfa was not adversely affected by soil moisture tensions less than 100 cm. of

water for six weeks. Oxygen contents were not known, but at moisture tensions below 100 the soil is nearly saturated with water. Furr and Aldrich (66), working in a saline alkali soil, found that oxygen contents between 0.4% and 2% for three weeks did not result in measurable injury to date palms. Rice has been preferred as a crop during reclamation of saline lands and will grow with roots submerged (204). It has a relatively low oxygen requirement and is able to transmit air through the stem to the roots, as in several other plants (88, 158).

Water absorption is also facilitated by oxygen supply (24, 244, 360). Newton found that barley respired more and used more energy to obtain water from solutions of high osmotic pressures (244). His series of nutrient solutions ranged from 0.1 to 6 atmospheres. It is believed that strawberry clover does well on saline soils primarily because of its ability to tolerate water-logged conditions (74).

The preceding sections have discussed ion intake as though it were a process of diffusion. Many look upon it as an ion exchange reaction in which, for example, the bicarbonate ion within the cell passes outward and exchanges for an incoming nitrate or chloride ion. Jacobs (150) has shown that the HCO_3 ion can very readily pass through the cell walls, especially where the pH of the outside solution is greater than inside the cells. In a similar way H^+ ion formed inside the cells would exchange for cations. The H^+ ion also has a very high rate of transfer.

In saline soils, which are usually calcareous, the pH value of the soil solution at normal moisture contents is about 7.0 to 8.0. In such an environment, according to the ideas of Jacobs, $HC0_3$ would rapidly pass out from the root cells permitting other anions to enter.

Steward and Preston (317), working with potato discs in potassium and calcium salts ranging from 0.75 to 75 milliequivalents per liter, concluded that the cations were the effective ions of the salts. Potassium salts acted conversely to calcium salts for most processes; thus potassium salts increased respiration whereas calcium salts with the same common anion depressed the process.

Lundegarth (201) does not agree with the theories of Hoagland and Steward concerning salt absorption. He claims that respiration is closely correlated with anion uptake.

The unequal rate of entry of various salts is dependent in part on

the rate at which one of the ions can be transported upward into the shoot. Of interest in this regard is the observation that in bean plants (77) sodium accumulated in the roots and was not transported upward, while in sugar beet, a salt-tolerant plant, sodium passed upward into the leaves in large amounts (56). Collander (41) has reported that halophytes take up large quantities of sodium, while *Fagopyrum esculentum, Zea Mays* and *Helianthus annuus* were distinguished by their large exclusion of Na.

Some plant species, such as those of *Statice, Frankenia, Tamarix* (117, 160, 287), *Saxifraga* (344), *Ameria* and *Plumbago* (284), have the faculty of carrying salts to the exterior of the leaves where they are precipitated and later lost by wind or rain. Other plants sometimes reduce their salt content by abscission of leaves high in salt. Thus Hayward and Long (unpublished) find the first peach leaves emerging in the spring have very high salt contents and show salt symptoms when grown on saline substrates. These leaves drop early; later leaves are more normal with lower salt contents and no visible symptoms of salt injury.

Antagonism

Many writers, particularly Osterhout (41, 97, 159, 240, 253, 254, 294), have published results indicating that plant growth is reduced by unfavorable proportions of ions. No attempt will be made to review the literature on antagonism. Thus Miyake (240) states: "potassium and magnesium or calcium salts are poisonous to the rice plant when used separately but when mixed together in suitable proportions the poisonous effect more or less completely disappears". He also indicated that antagonism between cations was greater than between anions, but several have felt that antagonisms between anions should not be dismissed (269, 317). This theory as to how alkali salts affect plants, dominant up to about 1930, has subsided because of tests which show the close relationship of growth depression to osmotic pressure, and that merely concentration of a favorable physiologically balanced solution produces reduced growth (110, 247, 294), while at high concentrations growth is reduced, no matter what the ionic proportion may be (159, 294) .

A particular case of physiological balance, that of the calcium-magnesium ratio, has received much attention, particularly in nutrient and sand culture solutions. It is believed that under certain

saline soil conditions unfavorable ratios may exist and reduce plant growth (194, 271).

The early investigators of salinity conditions noted that magnesium salts and sodium carbonate were particularly toxic (99, 308). Later reviews have been made by Miller (238) and Maximov (220). The early papers stressed that the best Ca : Mg ratios were about 2 : 1 or 1 : 1, although Gile (87) gives interesting data on rice in which high Ca : Mg ratios were toxic, especially in high concentration. Martin (218) states ratios of 1 : 1 or 1 : 3 are nontoxic to rice.

Magnesium is a constituent of chlorophyll, and calcium enters into the formation of the cell wall (44, 275, 314). With an excess of magnesium it is held that a normal calcium pectinate of the proper colloidal properties is not formed in the cell walls.

In soils, examples of unfavorable calcium : magnesium balance are rare. The normal soil is principally calcium saturated (130, 139), and calcium usually exceeds magnesium in the soil solution. Yet where the soil solution is obtained at low moisture contents, cases where magnesium exceeds calcium have been observed in a number of saline soils (213, soils 75, 83, 222, 86). The coastal soils of California seem to have more than normal amounts of exchangeable magnesium (167), and in some of these soils unfavorable Ca : Mg ratios may occur. Ratner (271), in reviewing Russian work, states that soils containing over 70% replaceable Mg are unfavorable to plant growth probably because calcium relations are disturbed. Tamhane (322) finds some Indian soils where magnesium salts are more toxic than sodium salts except Na_2CO_3.

Disturbed Metabolism

Although plant growth has been shown to be related to the osmotic pressure of the substrate, the mechanism of the action causing reduced growth is unknown. It has been suggested as being due to irreversible precipitation of protoplasm in cells with high osmotic pressures. Many believe that this is not directly a cause for reduced growth. Arguments are advanced that as a result of this physiological drought the normal nutrition of the plant is disturbed and reduced growth and, in some cases, death result from this disturbed nutrition. This can be discussed under several headings.

Nitrogen metabolism. pH values of western saline soils at normal moisture contents and carbon-dioxide pressures lies between 7.0 and 8.5 (71, 214, 276) and for alkali soils varies from 8.0 to 10.0. The pH value of the notorious sodium carbonate-containing soil from Vale, Oregon, is about 10.0 at field moisture (10.75 in a 1 to 5 extract (171)). This range of pH values and the nearly universal presence of calcium carbonate is believed conducive to nitrification, although it is indicated that formation of nitrates is restricted by soil conditions above pH 7.7 (39). Hence it is assumed that the greater part of the nitrogen is absorbed as nitrates in western irrigated regions.

Nightingale and Farnham (247) and Hayward and Long (110) grew plants at increasing osmotic concentrations obtained by concentrating the nutrient solution. Thus the ratios of ions was kept fairly uniform, but at the higher osmotic pressures the nitrogen supply was extraordinarily high. Both showed by anatomical examination, (247) with sweet peas up to 3 atm. and (110) with tomatoes up to 6 atm., that at high concentration the plants were in a high carbohydrate condition despite the presence of ample nitrate. Hayward and Long found that with increasing concentration the vascular bundles were reduced and parenchyma tissue increased on a relative basis with some starch accumulation. Hayward and Long also grew tomato plants with increasing osmotic pressure obtained by adding chloride or sulfate salts to a basal nutrient solution with similar results (110, 112).

Study of nitrogen and carbohydrate fractions in plants grown under varying osmotic pressures have been made (112, 247, 345, 346). The last two studies were made with beans. In the first study (247) the roots continued to absorb nitrates, but lost their ability to assimilate it at high osmotic pressures. As a result carbohydrates accumulated. In the study of Wadleigh and Gauch (346) the nitrogen level in the nutrient solutions was held constant. Their plants were grown during the winter with relatively low light conditions, and they were unable to note any increased starch accumulation at the higher osmotic levels.

In another study beans were grown in soil to which sodium chloride had been added in increasing amounts (345). At the close of the experiment the concentrations of salt in the soil solutions and the carbohydrate and nitrogen fractions of the beans were deter-

mined. In another portion of the experiment, soil moisture content was varied so that in one case there were several degrees of water stress, and in the second, several stages of physiological drought because of salt additions. In both series with increased "drought" there was an increase in nitrates and protein N, and little effect on reducing sugars. Addition of salt caused a large decrease in starch in the leaves. The authors concluded that with water stress, hydration of protoplasmic proteins was reduced, and suggested that other factors were operating to reduce growth besides water stress in the salt series, such as an effect of the chloride ion *per se*. Decrease in starch formation with wilting or high osmotic pressures are also reported (147).

Nightingale has reviewed the general subject of nitrogen metabolism (245), and Bakhuyzen (16) has reviewed and discussed protein synthesis and growth during the various growth stages of wheat. During the third, or catabolic, stages there is a breakdown of proteins and accumulation of carbohydrates similar to the accumulation of carbohydrates which occurs in high-salt plants. He shows that this is linked with reduced respiration and probably also reduced formation of auxin which may regulate respiration. Steward and Preston (317) state that potassium salts stimulate both respiration and protein synthesis from stored amino acids, while calcium salts retard the process. In calcium solutions nitrogen metabolism is diverted from amino acids to amide and ammonia. Phillis and Mason (260) suggest that potassium controls the rate of photosynthesis by regulating the rate at which carbon dioxide diffuses to the chloroplasts and the rate of movement of sugar from the chloroplast to the phloem. It is known that stomatal openings are reduced in cases of moisture stress (67, 68, 293).

Crops like sugar beet which normally store sugar will have a lower sugar content in the presence of high nitrates, even though this is accompanied by high salt substrate (115). Relationships between carbohydrate supply and absorption have recently been reviewed (139).

Other metabolic and specific ion effects. While there is overwhelming evidence that reduced plant growth in saline substrates is correlated with osmotic pressures, specific effects of certain ions on plant growth also exists.

The halophyte *Salicornia* had the highest germination and growth

in a soil mixture containing about 2% NaCl (334). It seemed to require the Na and Cl ions, and other salts with equal osmotic values were far less satisfactory.

Among agricultural plants effects associated with certain ions have often been noted in experiments in which comparisons were made at equal osmotic pressures. Chloride salts have frequently been found to be more toxic than sulfates. Thus Hayward and Long (111) reported death of peach trees at 3.2 atmospheres with chlorides, whereas trees were still alive with sulfates at 3.7 atmospheres. These trees ultimately died. Similar results were obtained with alfalfa (209).

On plotting yields against freezing point depressions from the data of Eaton (56), sulfates are found to be more toxic than chlorides at equal osmotic levels for alfalfa, cotton and sugar beets. Sulfates were found to be more toxic than chlorides for flax (114) and tomatoes (110).

While bicarbonates occur in large proportions in some irrigation waters, they are usually present in minor proportions in saline soil solutions. It is very difficult to determine whether the bicarbonate ion by itself is toxic because of the pH and carbonate ion relationships. Steward and Preston (316) found that potassium bicarbonate and dissolved carbon dioxide at constant pH, both reduce protein synthesis. In a three-dimensional diagram they show that protein synthesis in potato discs is at its maximum at about pH 6.5 and that concentrations of $KHCO_3$ above 5 m.e. per liter result in decreased protein synthesis. At 20 m.e. per liter protein synthesis is almost completely suppressed. The Arizona investigators (30, 229) feel that additional carbon dioxide in their soils would improve them by lowering the pH value and increasing phosphate availability.

In addition to this the cation associated with the bicarbonate ion is of extreme importance; if sodium it may lead to formation of an alkali soil, while if calcium it may be precipitated as $CaCO_3$.

The effect of cations on plant growth has been extensively investigated in various tests on antagonism. When calcium, magnesium and sodium are added singly to an otherwise adequate nutrient solution or sand culture, magnesium is more toxic than the other two (209, 347, 350). In part, this is attributed to unfavorable Ca : Mg ratios, or the phenomenon of antagonism which has been discussed previously. The very striking toxicity symptoms with guayule

(347) indicate that this plant is particularly sensitive to excessive magnesium. Calcium chloride was more toxic to barley than sodium chloride when compared on an equal osmotic basis (47). In experiments with flax on a podsol soil Smirnov (311) reported calcium to cause the greatest decrease in yield as compared with sodium and potassium. All were added as chlorides to produce equal osmotic levels.

Many writers have attributed the unfavorable effects of alkali salts to the sodium and chloride ions (273, 274). Repeated tests in which sodium chloride has been compared with calcium chloride has failed to show that it is unduly toxic in sand and solution cultures at isosmotic concentrations (75, 76, 77, 112, 114, 209, 216, 311, 319, 331, 347). In small amounts sodium is sometimes found beneficial to growth of sugar beets (191, 192) and asparagus (283). Sodium is accumulated in the roots of beans when grown in solutions of high sodium content (75), and this has also been found true for peaches (unpublished).

That chloride fertilizers may have some specific effect on reduction of chlorophyll has been suggested (19) and that as a result starch production is reduced (18). Breazeale (27) suggests that the alkali salts destroy the enzymes in the roots.

Germination and Seedling Growth

One of the processes associated with germination is imbibition which is governed by osmotic forces. It is natural, therefore, that imbibition should be retarded in salt solutions.

The Wyoming investigators as early as 1898 found that water imbibition and germination of the seeds used varied with the osmotic pressure of the salt solution (35, 36, 309, 310). Germination of wheat was prevented at about 10 to 14 atmospheres, while rye tolerated slightly larger amounts. Russian workers as early as 1912 (331) reported that germination of seeds was correlated with the osmotic pressure of the soil solution and found that isotonic salts gave approximately the same results (186).

Rudolfs (282) tested the germination of wheat, corn, watermelon, Canada field peas, white lupine, soybeans, rye and alfalfa at concentrations of various salts up to seven atmospheres. He concluded that "the rates of absorption are progressively retarded with an increase in the osmotic concentration values of the solutions which do

not react with the seed substance to modify in a chemical way the imbibing properties of the seeds" (109, 295, 330).

Hicks, working with fertilizer salts (124*a*), concluded that "the chief injury to germination from chemical fertilizers is inflicted upon the young sprouts after they leave the seed coat and before they emerge from the soil". Unpublished data (109) on wheat and alfalfa are in agreement with the above. Many other investigators (99*a*, 99*b*, 99*c*) using soils were unable to agree with the Wyoming workers, which can now be explained by the fact that through reaction with the soil the salt composition and concentration was changed, and that they were dealing with both emergence of the plumule from the seed and early growth of the seedling, or that they were working with alkali soils of low salinity and high content of exchangeable sodium.

Working with wheat seedlings in solutions, Harter (108*a*) found half of them died at normalities given: sodium chloride 0.05, sodium sulfate 0.04, sodium bicarbonate 0.026, sodium carbonate 0.01, magnesium chloride 0.009, and magnesium sulfate 0.007. This range corresponds to 0.8 atm. to 0.2 atm. These values seem exceptionally low. When mixed, or with calcium sulfate, the seedlings could tolerate much larger quantities, up to 0.2 N (about four atmospheres) except where sodium carbonate was present (162). Magnesium chloride alone was more toxic than sodium or calcium chlorides (215).

The need for oxygen during germination and seedling growth was shown in reports (343) that barley root and shoot growth was considerably diminished at pressures below 9.5% oxygen, while rice grew well at oxygen pressures as low as 3%. Temperature is also an important factor in germination and early growth. Thus Ogasa (250) found the maximum concentration for germination of soybeans to be 0.3 N NaCl at 15° C. and only 0.2 N NaCl at 30° C. Edwards (59) reported the optimum temperature for soybean germination to be 33–36.5° C., while 28–31° C. yielded the longest seedlings. Ahi and Powers (2) found the best temperature for germination to be 55° F., and at this temperature strawberry clover would tolerate 5,600 p.p.m. of sea salts. Alfalfa withstood somewhat less.

Fertilizer injury to seeds and reduction in stand is also an osmotic phenomenon similar to the action of alkali salts (270, 330). It thus

appears that seeds will germinate (*i.e.*, plumule emerge) at higher osmotic pressures than the shoot will tolerate later in its growth period, but germination at high osmotic pressures retards germination and probably results in a weakened radicle and plumule.

PLANT RELATIONS TO ALKALI SOILS

As indicated previously alkali soils are those which contain considerable replaceable sodium. On reduction of the electrolyte content in such soils the replaceable sodium will hydrolyze to give soil pH values which are usually above 8.5, and the soil will disperse.

Plants growing in alkali soils having a high salt content have the same ills as those in saline soils and in addition may suffer from actual lack of water, lack of oxygen in the soil air, and many nutritional disorders as a result of impermeability to water, plant food unavailability, and high pH values.

A number of investigators (11, 28, 30, 124, 128, 229, 255, 329) have attributed poor plant growth on alkali soils in large part to the unfavorable physical conditions in such soils, and because many alkali soils are dispersed or puddled, Arizona investigators have made a study of plant growth conditions in puddled soils (226, 231).

Puri (265) reported studies relating yield of wheat to degree of alkalisation on two soils in the Punjab. His degree of alkalisation is the per cent saturation of the soil complex by Na + K. He reported that, on the Montgomery soil, yields increased from 32 pounds per acre with 67% saturation to over 1,000 pounds per acre with the replaceable sodium reduced to about 20% on soils treated with calcium chloride and leached. Similar results were obtained with a Kala Shak Kaku soil, the correlation coefficient between degree of alkalisation and yield for the two soils treated separately being 0.85. Similar results were obtained elsewhere (362). Replaceable magnesium in excess of 19% of capacity augments the depressing effect of replaceable sodium on crop yields (252). Ratner (271, 272) grew oats and wheat in a chernozem soil saturated with sodium to varying percentages. In pot cultures growth was good up to about 50% sodium. Naturally occuring solonetz soils in pots planted to oats, wheat and barley gave lower yields with 30% replaceable sodium than with 10% replaceable sodium. Presumably in these pots aeration was good. Gedroix (84) planted oats, and in some cases buckwheat and mustard in soils saturated

with the various bases including sodium. He did not obtain normal growth unless exchangeable calcium accounted for a major portion of the exchange capacity, although strontium-saturated soils gave fair yields.

Soils of Low Permeability

Alkali soils containing a considerable amount of soluble salts (saline alkali soils) are usually permeable because the salts present maintain the soil colloids in a flocculated condition. As the soluble salt concentration is reduced by irrigation water the flocculative effect of the soil solution is reduced, soil structure is broken down, the clay disperses and the finely divided clay particles thus separated fill up the finer capillaries and reduce or prevent movement of water and air. The effect of electrolytes on soil floccculation can best be explained on the basis of zeta potential (157). They found that sodium-saturated soils have high zeta potentials, and it requires two to ten times as much of sodium salts in solution as on the colloid to reduce the zeta potential below a critical value and so produce flocculation. Calcium-saturated soils have a much lower zeta potential, and far less calcium salts in solution are required to produce flocculation. As an example of this, Reitemeier and Christiansen (unpublished), working with an Indio fine sandy loam, one part of soil to two of water, found 12 m.e./liter of a calcium salt was necessary to produce flocculation with a 25% Na-saturated soil, while only 2 m.e./liter was sufficient with a 10% Na-saturated soil.

Other theories concerning the cause of impermeability in soils have been prepared. Scofield (289) has suggested that on leaching out salts of alkali lands, sodium and other soluble silicates are precipitated in the soil closing the capillaries. Kelley and Brown (171, 232, p. 265) have shown that soluble sodium silicate can be found in some alkali soils. Arizona investigators (232) and Kowda (187) also suggest that aluminum hydroxide is present and may be precipitated in the pore spaces.

In a comprehensive study of alkali soils Gardner (71) found that permeability decreased with clay content and exchangeable sodium content, but that replacement of the sodium by calcium did not result in increased permeability unless the soil was first dried.

Men at the Punjab Irrigation Research Institute have recognized that dispersion of alkali soils is one of the major reasons for poor plant growth. The degree of dispersion (in per cent of complete

dispersion of all the clay and called "dispersion coefficient") is governed largely by the percentage of replaceable sodium (10, 61, 64, 98, 134, 184, 185, 189a, 242, 263, 267, 290, 355), but modified too by salt content (14, 61, 266, 323). Ratner (272) and Kotzman (185) claim that even as little as 5% replaceable sodium increases dispersion, while one author (14) indicates that soils containing as little as 3% Na may have some alkali soil properties. Of interest is the observation that when rice is grown in alkali soils over pH 8.8, soluble salts may be beneficial because of the flocculative action on soil colloids (234).

Working with electrodialysed acid clays, Bradley, Grim and Clark (26) showed that as the montmorillonite clay crystal took on additional water, it swelled, and as the water content increased to 65%, corresponding to 24 molecules of water per unit cell, no distinct X-ray patterns could be obtained, thus indicating that the plates forming the soil crystal were free and probably dispersed. These dispersed colloidal platelets, previously forming a crystal, can move about in the soil solution and may close the soil capillaries.

As irrigation water removes the accumulated salts, the soil will disperse when the salt concentration is reduced below certain critical limits. This is often called "freezing up", and at this stage permeabilities (71, 212) may be as low as a few inches a year. A good growing crop in the Southwest such as alfalfa may require 60 inches of water per year. Clearly, if the rate with which water can enter the soil is less than 60 inches a year, this plant can not get enough water for maximum growth even though the soil is covered with water the year round. The plant then, on some heavy alkali soils, can suffer from lack of soil water as well as lack of soil oxygen and other causes.

Many crops grown in heavy soils of humid regions have been found to suffer from lack of oxygen in the soil air. In alkali soils having low permeabilities to water it is very likely that the soil air is deficient in oxygen. There seem to be very few data on this subject from alkali soils.

Nutrient Unavailability and Chlorosis

Chlorosis is very prevalent on irrigated land throughout the West and particularly in the northwestern States. It is usually associated with calcium carbonate in the soil at a depth of less than three

feet. The crops affected most frequently are grapes, pears, soft maple, cottonwood, brambles, peaches, roses, apples, prunes, globe locust and citrus (20, 315, 354). This chlorosis is considered lime-induced because applications of iron as sprays or injections give some benefit, but often not enough to be economical (20, 193). In some localities zinc and boron deficiency are also present. Guest (96), in a study of citrus nutrition, reported that citrus grew chlorotic at pH 7.0 in the presence of 1% coarse magnetite but grew well at the same pH value if the magnetite was finely ground. He attributed the increased growth with finely ground magnetite to greater root-contact surface and absorption of iron. This suggests that in calcareous soils trees may become chlorotic because the area of contact between roots and iron-containing soil minerals is decreased to a low value, and that as regards iron at least, contact feeding may be relatively important (153, 155).

Soil reaction. Whitney and Gardner (361) have recently studied the effect of carbon dioxide on soil reaction. They find that the pH value is approximately a straight line function of the logarithm of the carbon dioxide pressure. Thus for a black alkali soil (Gila series), pH values at 1:2 suspension varied from 9.20 at 0.003 atmosphere carbon dioxide to 7.06 at 0.1126 atmosphere carbon dioxide. The carbon dioxide content of the soil air in the vicinity of the root may be very low unless the plant is growing vigorously. In soils which do not contain appreciable absorbed sodium or sodium carbonate the pH values at carbon dioxide contents up to 20% would probably range from 8.2 to 6.5. The pH value of a soil varies with its content of $CaCO_3$, $MgCO_3$, Na_2CO_3, replaceable base status, carbon dioxide pressure, salt content and dilution.

Mehta in the Punjab (234) has correlated rice yields with pH and soluble salt content. Above pH 8.8 yields decrease, likewise if the salt content exceeds 0.24%. Since the rice was flooded this salt concentration in atmospheres was probably low. The soil pH values are related to the degree of sodium saturation (265), and it is inferred that the soils are unproductive at high pH values because of the poor physical condition. When the soil pH is as low as 8.8 the growth of other crops less tolerant than rice can be considered (234).

Plants grown on soils containing calcium carbonate often have saps of high pH values which reduce iron solubility and mobility

(196, 197). Plant sap pH value and soluble iron content also varies with light intensity (148, 197) and nitrate level (348).

Calcium. McGeorge (225) has suggested that in the soil solution of alkali soils the carbon dioxide content and calcium ion content are low. This is also indicated by analyses of chlorotic leaves of trees grown on areas which indicate a low calcium content and probably low calcium availability (227). Further evidence of low quantities of soluble calcium is given by negative calcium absorption in Neubauer tests on such soils (228). Magistad and Reitemeier (213), in their analyses of soil solutions at low soil moisture contents, reported two cases in which the calcium content was 6.4 and 6.9 milliequivalents per liter. This quantity continuously supplied is considered more than ample for plant growth, but there may be other soils which are more deficient in soluble calcium or in which the supplying power of the soil is meager. Ratner (271, 272) also concludes that plants suffer for lack of calcium in high sodium soils and states: "The destruction of plant life in pot experiments when there is a large amount of exchangeable Na is difficult to explain (in the case of non-carbonate soils) by the alkaline reaction of the medium, by the accumulation of soda, or by the unfavorable physical properties of the soil. One of the possible causes of the destruction of plant life may be assumed to be the breaking down in the soil of the calcium regime, and in particular an insufficiency of calcium as one of the elements of plant nutrition". A similar concept has been expressed elsewhere (11).

An excellent review of the role of calcium for higher plants was published in 1938 (183), listing three hypotheses on the action of calcium on plant roots:

a. Loew's: That the cell nucleus requires specific ions such as calcium.

b. Kisser's: That a lack of calcium results in disintegration of the cell wall.

c. Hansteen-Cranner hypothesis: That single ions can act as toxic agents on the cell wall or prevent such toxic action.

This author also discusses a number of articles indicating that in plants calcium has a regulating action on the water content, modifies carbohydrate and nitrogen transformations, respiration, enzymes, germination and laying down of tissue. It also forms calcium pectates in the middle lamella having desirable properties. See also (246).

There appears to be some similarity between strongly acid soils and soils high in replaceable sodium or magnesium, in that in each case the plant may be unable to obtain an adequate supply of calcium. Albrecht and his students (4, 5, 6, 7, 92, 144, 264) and others (84, 86, 208, 233, 261, 333) have indicated that plants suffer for lack of calcium in acid soils rather than because of the H-ion concentration. Alkali soils which have a low content of replaceable calcium and conversely a high percentage of replaceable sodium or magnesium are also believed to reduce plant growth because of calcium deficiency. The work of Jenny and associates (152, 154, 155) has demonstrated that in contact with clays, plant roots may lose large amounts of ions to the clay by contact depletion. Of particular interest are the experiments of Van Itallie (149) who grew Italian rye grass in soils saturated principally with calcium, magnesium, sodium and potassium, respectively. The amount of cation in the plant correlated with the percentage of that cation on the exchange complex. Thus soils low in exchangeable calcium and magnesium, and high in sodium, produced a crop having a high Na content, and growth was somewhat reduced.

In studies on germination of barley in alkali soils Kelley (164) reported that the soil solution in contact with the seeds did not materially reduce germination but that the seeds in contact with the alkali soil failed to germinate properly. He believed this to be caused by the avidity of the soil complex for calcium, even to the point of removing calcium from the barley seed and roots. Similar experiments in which "bara" soils, freed from salts by washing, still prevent germination are reported (108). The author explains the phenomenon on the basis of formation of black alkali in the absence of soluble salts, but Kelley's hypothesis seems more plausible. In harmony with this concept, Tiedjens and Schermerhorn (326), in discussing greenhouse problems, state: "The ratio of available calcium to potassium or sodium was extremely important for germination of seed and growth of vegetable crops on coastal plain soils".

Russian workers (252, 272) indicate that plant growth is not seriously affected in non-saline alkali (solonetz) soils until the percentage of replaceable sodium exceeds 40. Their experiments were conducted in pots carefully watered so the unfavorable physical effects of sodium were minimized. They also attribute lack of growth at high replaceable sodium percentages to lack of calcium

and report that replaceable magnesium lowers the threshold of sodium toxicity, as also does organic matter and calcium and magnesium carbonates. Ratner (272) suggests that calcium and magnesium carbonates may increase the unfavorable effect of sodium because of the formation of small amounts of sodium carbonate in the soil. The harmfulness of organic matter is attributed to increased alkalinity due to hydrolysis of Na-humate, to direct toxicity of Na-humate, and to additional mobilization of calcium. (Authors probably meant immobilization (252)).

Chlorosis of trees on calcareous and alkali-calcareous soils may possibly be caused by a low calcium supply, since the leaves of such trees often have a high potassium and low calcium content (193, 225, 352, 353). In experiments with alfalfa in soils of various Ca/K ratios, the Ca/K ratio in the plant was found to correlate with that in the soil (145). Peech and Bradfield (257) have recently reviewed calcium-potassium relationships in soils and plants and conclude that plants absorb large amounts of potassium because large amounts are available and that large amounts of available potassium decrease calcium absorption. Alkali soils often have several milliequivalents of replaceable potassium per 100 grams, far more than humid soils, and the low calcium content of chlorotic leaves may therefore be associated with an unfavorable K/Ca balance in the soil solution. Reference to the table on page 183 shows that alkali soils tend to have a higher relative proportion of replaceable potassium.

Magnesium. There appears to be no evidence of magnesium deficiency in alkali soils. Supranormal amounts of replaceable magnesium leads to unfavorable calcium-magnesium relations. Ratner (271), in reviewing this, states that the experiences of several Russian investigators have shown that with magnesium up to 50–60% of the replaceable capacity there is no decrease in yield, but above this there is a sharp decrease in plant growth. He interprets this as additional evidence that conditions such as high Na or Mg will limit calcium availability and intake by the plant and thus reduce growth. Several soil analyses from coastal California are listed (167) in which magnesium constitutes over 50% of the base exchange capacity. McIntire and Young (202) grew tall oat grass and cowpeas in soils to which MgO and $MgCO_3$ had been added. During the first year germination was poor, chlorosis appeared and

yields were low. At the end of a year this toxicity had disappeared. When the soils were leached at the time of harvesting cowpeas, magnesium salts greatly exceeded calcium in the leachate.

Iron and manganese. Shive (296) has indicated that the familiar lime-induced chlorosis is a disturbance of the soluble iron-manganese ratio in the plant. Thus chlorosis might be caused by iron being too low and remedied by applications of iron as a spray, by tree injections or soil applications. Sometimes manganese is too low, and such cases are remedied by manganese applications (217).

As Thorne and Wallace (325) have pointed out, chlorosis on high-lime soils (and almost all alkali soils are high in lime) is generally due to a deficiency of either iron or manganese to the plant. They indicate that ferrous iron can not exist in appreciable quantities in normal calcareous soil. Ferrous iron availability then depends on the reducing ability of the root. There may also be a disturbance of ferric-ferrous relations within the plant.

Anions. The anions essential to the growth of plants are usually abundant in the soil solutions of alkali soils, with the exception of nitrates and phosphates. Breazeale and McGeorge (30, 230) state that few, if any, black alkali soils contain sufficient black alkali to be directly toxic to plant growth, but that the plants are unable to absorb the necessary plant foods, including nitrates and phosphates, at pH values above about 8.0. In well aerated soils the root can grow and excrete sufficient carbon dioxide to reduce the pH value of the local root environment so as to facilitate plant food absorption, primarily that of phosphates. Addition of organic matter which yields carbon dioxide improves plant growth on alkali soils.

Buehrer (34) has calculated the relative concentrations of the various phosphate ions at pH ranges from 3 to 10, and shows that on the acid side HPO_4^{--} is the prevailing ion. In alkaline solutions it is $H_2PO_4^{--}$. While chemical analyses show an ample supply of soluble phosphorus in soil solutions of alkali soils, this phosphorus is presumably present as $H_2PO_4^{--}$ and the plant does not seem to absorb it readily. On such soils phosphate fertilization is often beneficial (30).

Absorption of nitrate ions is not markedly retarded at pH values up to 8.0 (13, 140, 247), but its intake is governed by the rate with which it is removed from the root cells and transported to the rest of the plant. In the field, nitrate absorption must be satisfactory in

calcareous soils because excellent crop yields are often obtained. Nitrate formation is greatly reduced in alkali soils and probably does not occur above pH 7.7 (39).

Corrosive and Toxic Substances

Workers since the time of Hilgard in 1886 (125) have noted that sodium carbonate in soils is actually corrosive to plants, usually at the soil surface level or crown of the plant (125, 143, 358). Many of the older soil analyses report more sodium carbonate than was actually present, but there is no question that many alkali soils contain substantial amounts of sodium carbonate as such.

Magistad (206) found that at pH values above 9.0 appreciable amounts of aluminum were in solution as aluminates and suggested that very alkaline soils do not support plant growth because of the soluble aluminates present. Some salty soils from the humid climate of Finland contain a high content of alum (1), and others (187, 232) also consider that aluminates are present in some alkali soils.

Plant Tolerance to Salty Soils

The literature on this subject is profuse, and it is impossible to review it in this article. Most of the data on tolerance fails to take into consideration the distinction between saline and alkali soils, and the effect on the plant may be quite diverse. Furthermore, most of the data is given in terms of per cent salt in the soil without reference to water content, so that osmotic pressures in the soil solution can not be calculated (163, 200).

Peaches are among the crops least tolerant to salinity conditions, dying at about 3.0 atmospheres (111). On the other hand, alfalfa and cotton are among the most tolerant and are reduced in yield about 20% at osmotic presures of 4.0 atmospheres (210).

Tolerance to high osmotic conditions may not carry with it tolerance to alkali conditions, particularly high percentages of replaceable sodium. Thus it is suggested (252) that peas, because of their high calcium requirement, will not tolerate as much replaceable sodium as wheat. The experiments confirmed this.

SUMMARY

About 350 papers are reviewed on the subject of plant relations in saline and alkali soils. The fields stressed are: the classification

and composition of saline and alkali soils and the physiological responses of plants grown in soils of these two types. Papers dealing with reclamation of alkali land, cultural practices, tolerance of various plant species to salinity and alkali conditions, and ecological relationships are omitted.

A distinction is made between saline and alkali soils in accordance with the classification of such soils by de Sigmond. Saline soils have high salt contents—at least 0.1% in the case of chloride salts and 0.2% where sulfate salts predominate. Alkali soils contain at least 12% of exchangeable sodium plus potassium in terms of the exchange capacity of the soil. The threshold of 12% is taken provisionally because soils containing this amount of exchangeable alkali bases have impaired physical characteristics. There are gradations and combinations of saline and alkali soils so that four main classes are recognized: saline soils, saline alkali soils, slightly saline alkali soils and degraded alkali soils (alkali soils with a very low salt content).

In saline soils the principal factor depressing plant growth is the decrease in available water due to the high osmotic pressure of the soil solution. Of interest in this connection are the data of Rosene, and Hayward and Spurr which show by direct measurement that water absorption is reduced as the osmotic pressure of the substrate is increased. Some investigators attribute decreased growth in saline soils to the harmful effects of specific ions. Such effects are known to exist, but in most cases they appear to be less important than the inhibition resulting from high osmotic pressure.

Many reasons are listed why a reduction in water intake decreases plant growth. These include salting out of cellular proteins, shrinkage of cell contents from cell wall, irreversibility of hydration of cell contents and interference with ion accumulation.

Plants require considerable oxygen in the substrate for absorption of water and minerals. Many alkali soils are water-logged with low oxygen contents in the soil air, and this lack of oxygen is believed to reduce plant growth.

Plants growing in saline soils are subjected to high concentrations of certain salts and to salts which are not in the most favorable ratios for plant growth. Under such conditions several authors have found that the nitrogen compounds are not assimilated, carbohydrates accumulate and the growth rate is reduced. On the other

hand, it has been shown that starch formation may also be inhibited by high chloride concentrations.

In alkali soils having large contents of replaceable sodium, the soil takes on unfavorable physical properties. It disperses, does not drain well, the soil air may be low in oxygen, and the soils do not "take" irrigation water. The presence of considerable amounts of salts or electrolytes in soils overbalances or minimizes the unfavorable effect of exchangeable sodium on the dispersion of soils. When such salts are removed from a saline alkali soil the unfavorable physical effects are accentuated.

A number of authors ascribe the unfavorable effects of alkali soils on plants to a breakdown of the calcium regime in addition to unfavorable physical conditions. The soil solution in equilibrium with alkali soils is very low in calcium and high in sodium.

In addition to unfavorable physical condition and lack of calcium, alkali soils usually have high pH values, with attendant unavailability of several essential elements such as iron, manganese, phosphates, and at times nitrates.

In alkali soils of low salt content some sodium carbonate is present. The alkali carbonates are very toxic and even corrosive to plant parts. Probably only in the most extreme cases is there any appreciable amount of free sodium carbonate.

Soil solutions of high osmotic pressures are not confined to the saline soils of the West, but may also occur as a result of heavy applications of soluble fertilizer, especially on sandy soils.

A distinction is made between the characteristics of saline and alkali soils, since it is believed that the physiological reactions of the plant are different under the two sets of conditions. It follows that a plant may be tolerant to one soil type and not to the other.

LITERATURE CITED

1. Aarnio, B. Salt soils (alum soils) of the humid climate of Finland. Int. Mitt. Bodenk. **12**: 180–185. 1922; Exp. Sta. Rec. **50**: 15.
2. Ahi, S. M. and W. L. Powers. Salt tolerance of plants at various temperatures. Pl. Physiol. **13**: 767–789. 1938.
3. Alben, A. O. Reactions of electro dialyzed humus and bentonite and application of the method. Jour. Am. Soc. Agron. **22**: 311–326. 1930.
4. Albrecht, W. A. Calcium and hydrogen ion concentration in the growth and inoculation of soy beans. Jour. Am. Soc. Agron. **24**: 793–806. 1932.
5. ————. Absorbed ions on the colloidal complex and plant nutrition. Proc. Soil Sci. Soc. Am. **5**: 8–16. 1940.

6. ————. Plants and the exchangeable calcium of the soil. Am. Jour. Bot. **28**: 394–402. 1941.
7. ————. Soil acidity. A nutrient deficiency. Sci. Mon. **58**: 237–238. 1944.
8. ALDRICH, D. G. *et al.* Hydration control of montmorillonite as required for its identification and estimation by X-ray diffraction methods. Soil Sci. **57**: 215–231. 1944.
9. ALEXANDER, L. T. *et al.* Minerals present in soil colloids. II. Estimation in representative soils. Soil Sci. **48**: 273–279. 1939.
10. ANDRIANOV, K. S. The nitrate solonchaks of the Isfarin region of the Tadzhik S. S. R. Khim. Sotsial. Zemled. No. **10**: 63–67. 1936; Chem. Abs. **31**: 6792.
11. ANTIPOV-KARATAEV, I. N. Über die Meliorierung der Alkaliböden unter Irrigationsbedingungen in der Ud. S. S. R. Trans. 6th Comm. Int. Soc. Soil Sci. Vol. B: 474–481. (Zurich). 1937.
12. ———— *et al.* The laws governing the interaction of clays and soils with electrolytes. Trans. Dokuchaev Soil Inst. (U.S.S.R.) **20**: 5–32. [English summary] 1939; Chem. Abs. **34**: 4845.
13. ARNON, D. I. *et al.* Hydrogen ion concentration in relation to absorption of inorganic nutrients by higher plants. Pl. Physiol. **17**: 515–524. 1942.
14. ASGHAR, A. G. *et al.* Soil deterioration in the canal-irrigated areas of the Punjab. Part II. Relation between degree of alkalisation and dispersion coefficient in deteriorated soils. Punjab Irrig. Res. Inst., Res. Publ. **4**(8). 1935.
15. AYERS, A. D. *et al.* The interrelationships of salt concentration and soil moisture content upon the growth of beans. Jour. Am. Soc. Agron. **35**: 796–810. 1943.
16. BAKHUYZEN, H. L. VAN DE SANDE. Studies on wheat grown under constant conditions. 1937.
17. BARNES, J. H. AND B. ALI. Alkali soils: Some biochemical factors in reclamation. Agr. Jour. India **12**: 368–389. 1917.
18. BASSLAVSKAYA, S. S. Influence of the chloride ion on the content of carbohydrates in potato leaves. Pl. Physiol. **11**: 863–871. 1936.
19. ———— AND M. SYROESHKINA. Influence of the chloride ion on the content of chlorophyll in the leaves of potatoes. Pl. Physiol. **11**: 149–157. 1936.
20. BLODGETT, E. C. Chlorosis of horticultural crops in Idaho. Northwest Fert. Conf. Hort. Pullman, Washington, January 15–16, 1943.
21. BODMAN, G. B. AND P. R. DAY. Freezing points of a group of California soils and their extracted clays. Soil Sci. **55**: 225–246. 1943.
22. BOYNTON, D. AND O. C. COMPTON. Effect of oxygen pressure in aerated nutrient solution on production of new roots and on growth of roots and tops of fruit trees. Proc. Am. Soc. Hort. Sci. **42**: 53–58. 1943.
23. ———— AND ————. Normal seasonal changes of oxygen and carbon dioxide percentages in gas from the larger pores of three orchard subsoils. Soil Sci. **57**: 107–117. 1944.
24. ———— *et al.* Are there different critical oxygen concentrations for the different phases of root activity? Science **88**: 569–570. 1938.
25. ———— AND WALTER REUTHER. Seasonal variation of oxygen and carbon dioxide in three different orchard soils during 1938 and its possible significance. Proc. Am. Soc. Hort. Sci. **36**: 1–6. 1938.
26. BRADLEY *et al.* The behavior of montmorillonite upon wetting. Zeit. Kristal. **97**: 216–222. 1937.
27. BREAZEALE, J. F. Alkali tolerance of plants considered as a phenomenon of adaptation. Ariz. Agr. Exp. Sta., Tech. Bul. 11. 1926.
28. ————. A study of the toxicity of salines that occur in black alkali soils. Ariz. Agr. Exp. Sta., Tech. Bul. 14. 1927.

29. ———— AND W. T. McGEORGE. Sodium hydroxide rather than sodium carbonate the source of alkalinity in black alkali soils. Ariz. Agr. Exp. Sta., Bul. 13. 1926.
30. ———— AND ————. Nutritional disorders in alkali soils as caused by deficiency of carbon dioxide. Ariz. Agr. Exp. Sta., Tech. Bul. 41. 1932.
31. BRENCHLEY, WINIFRED E. The effect of the concentration of the nutrient solution upon wheat cultures. Ann. Bot. **30**: 77–91. 1916.
32. BRIGGS, L. J. AND H. L. SHANTZ. The relative wilting coefficient for different plants. Bot. Gaz. **53**: 229–235. 1912.
33. ———— AND ————. The wilting coefficient for different plants and its indirect determination. U. S. Dept. Agr., Bur. Plant Ind., Bul. 230. 1912.
34. BUEHRER, T. F. The physiocochemical relationships of soil phosphates. Ariz. Agr. Exp. Sta., Bul. 42. 1932.
35. BUFFUM, B. C. Alkali: Some observations and experiments. Wy. Agr. Exp. Sta., Bul. 29. 1896.
36. ————. Alkali studies. III. *In* Wy. Agr. Exp. Sta., Ann. Rep. pp. 1–40. 1899.
37. BURGESS, P. S. Alkali soil studies and methods of reclamation. Ariz. Agr. Exp. Sta., Bul. 123. 1928.
38. CALDWELL, J. S. The relation of environmental conditions to the phenomenon of permanent wilting in plants. Physiol. Res. **1**: 1–56. 1913.
39. CASTER, A. B. *et al.* The micro-biological oxidation of ammonia in desert soils. I. Threshold pH value for nitratification. Ariz. Agr. Exp. Sta., Tech. Bul. 96. 1942.
40. COLLANDER, R. Permeabilitäts-studien an Characeen. III. Die Aufnahme und Abgabe von Kationen. Protoplasma **33**: 215–257. 1939.
41. ————. Selective absorption of cations by higher plants. Pl. Physiol. **16**: 691–720. 1941.
42. CONNER, S. D. Excess soluble salts in humid soils. Jour. Am. Soc. Agron. **9**: 297–301. 1917.
43. DAVIS, R. O. E. AND H. BRYAN. The electrical bridge for the determination of soluble salts in soils. U. S. Dept. Agr., Bur. Soils, Bul. 61. 1910.
44. DAY, D. Some effects of calcium deficiency on *Pisum sativum*. Pl. Physiol. **4**: 493–506. 1929.
45. DAY, P. R. The moisture potentials of soils. Soil Sci. **54**: 391–400. 1942.
46. DEMIDENKO, T. T. AND N. P. MARTYNOV. Effect of osmotic pressure of the soil solution on yield and composition of sugar beet. Comp. Rend. Acad. Sci. (U.S.S.R.) **15**: 371–374. 1937; Chem. Abs. **31**: 8785.
47. DIVISION OF AGRICULTURAL CHEMISTRY. Rep. Cal. Agr. Exp. Sta. pp. 24, 27. 1921.
48. DORSEY, C. W. Alkali soils of the United States. A review of literature and summary of present information. U. S. Dept. Agr., Bur. Soils, Bul. 35. 1906.
49. DOUGHTY, J. L. AND H. E. STALWICK. The effect of alkali salts on plant growth. Sci. Agr. **20**: 272–276. 1940.
50. DRABBLE, E. AND HILDA DRABBLE. The relation between the osmotic strength of cell sap in plants and their physical environment. Biochem. Jour. **2**: 117–132. 1907.
51. DUNKLE, E. C. AND F. G. MERKLE. The conductivity of soil extracts in relation to germination and growth of certain plants. Soil Sci. Soc. Am., Proc. **8**: 185–188. 1943.
52. EATON, F. M. The water requirement and cell sap concentration of

Australian salt bush and wheat as related to the salinity of the soil. Am. Jour. Bot. **14**: 212–226. 1927.
54. ————. Salinity of irrigation water and injury to plants. Cal. Citrog. **20**: 302, 322–326, 334, 362–365. 1935.
55. ————. Water uptake and root growth as influenced by inequalities in the concentration of substrate. Pl. Physiol. **16**: 545–564. 1941.
56. ————. Toxicity and accumulation of chloride and sulfate salts in plants. Jour. Agr. Res. **64**: 357–399. 1942.
57. ———— and V. P. Sokoloff. Absorbed sodium in soils as affected by the soil water ratio. Soil Sci. **40**: 237–247. 1935.
58. Edlefsen and A. B. C. Anderson. Thermodynamics of soil moisture. Hilgardia **15**: 31–298. 1943.
59. Edwards, T. I. Relations of germinating soybeans to temperature and length of incubation time. Pl. Physiol. **9**: 1–30. 1934.
60. Ellis, J. H. and O. G. Caldwell. Magnesium clay "solonetz". Trans. Third Int. Cong. Soil Sci. Vol. 1: 348–350. 1935.
61. Fireman, M. and G. B. Bodman. The effect of saline irrigation water upon the permeability and base status of soils. Soil Sci. Soc. Am., Proc. **4**: 71–77. 1939.
62. ———— and O. C. Magistad. [Unpublished].
63. Fitting, H. Die Wasserversorgung und die osmotische Druckverhältnisse der Wüstenpflanzen. Ztsch. Bot. **3**: 209–275. 1911.
64. Fitts, J. W. *et al.* "Slick spots" in Nebraska. Jour. Am. Soc. Agron. **31**: 823–831. 1939.
65. Fraps, G. S. The effect of salt water on rice. Texas Agr. Exp. Sta., Bul. 122. 1909.
66. Furr, J. R. and W. W. Aldrich. Oxygen and carbon dioxide changes in the soil atmosphere of an irrigated date garden on calcareous very fine sandy loam. Proc. Am. Soc. Hort. Sci. **42**: 46–52. 1943.
67. ———— and E. S. Degman. Relation of moisture supply to stomatal behavior of the apple. Proc. Am. Soc. Hort. Sci. **28**: 547–551. 1932.
68. ———— and J. R. Magness. Preliminary report on relation of soil moisture to stomatal activity and fruit growth of apples. Proc. Am. Soc. Hort. Sci. **27**: 212–218. 1931.
69. Gangulee, N. The alkali soils of India. Actes IV Int. Conf. Pedologie, 2nd Comm: 643–655. 1924.
70. Gapon, E. N. On the theory of exchange adsorption in soils. Jour. Gen. Chem. (U.S.S.R.) **3**: 144–163. 1933.
71. Gardner, R. Some soil properties related to the sodium salt problem in irrigated soils. U. S. Dept. Agr., Circ. [In press].
72. ———— *et al.* Slick spots in western Colorado soils. Col. Agr. Exp. Sta., Bul. 20. 1937.
73. Gauch, H. G. and F. M. Eaton. Effect of saline substrate on hourly levels of carbohydrate and inorganic constituents of barley plants. Pl. Physiol. **17**: 347–365. 1942.
74. ———— and O. C. Magistad. Growth of strawberry clover varieties and of alfalfa and ladino clover as affected by salt. Jour. Am. Soc. Agron. **35**: 871–880. 1943.
75. ———— and C. H. Wadleigh. The influence of saline substrates upon the absorption of nutrients by bean plants. Am. Soc. Hort. Sci., Proc. **41**: 365–369. 1942.
76. ———— and ————. Effects of high salt concentrations on the growth of bean plants. Bot. Gaz. **105**: 379–387. 1944.
77. ———— and ————. The effect of high concentrations of sodium, calcium, chloride, and sulfate on ionic absorption by bean plants. Soil Sci. [In press].

78. Gedroix, K. K. Colloidal chemistry as related to soil science. Zhurnal Opitnoi Agronomii **13**: 363–412. 1912. [Trans. by Waksman].
79. ————. The absorping capacity of the soil and the zeolitic basis of the soil. Zhurnal Opitnoi Agronomii **17**: 472–527. 1916. [Trans. by Waksman].
80. ————. Saline soils and their improvement. Zhurnal Opitnoi Agronomii **18**: 122–140. 1917. [Trans. by Waksman].
81. ————. On the absorptive power of soils. Ed. Com. People's Com. Agr., 1922. [Trans. by Waksman].
82. ————. Soil absorbing complex and the absorbed soil cations as a basis of genetic soil classification. People's Com. Agr., Nossov Agr. Exp. Sta., Agrochem. Div., Paper No. 38. 1925. [Trans. by Waksman].
83. ————. Der adsorbierende Bodenkomplex. [Trans. by H. Kuron]. 1929.
84. ————. Exchangeable cations of the soil and plant: I. Relation of plant to certain cations fully saturating the soil exchange capacity. Soil Sci. **32**: 51–63. 1931.
86. Gehring, A. *et al.* Untersuchungen ueber die Feststellung des Kalkbedurfnisses Braunschweighischer Böden. Trans. Sec. Comm. Int. Soc. Soil. Sci. A: 153–169. 1926.
87. Gile, P. L. Lime magnesia ratio as influenced by concentration. Porto Rico Agr. Exp. Sta., Bul. 12. 1912.
88. Glasstone, Violette C. Passage of air through plants and its relation to measurement of respiration and assimilation. Am. Jour. Bot. **29**: 156–159. 1944.
89. Glinka, K. Die Typen der Bodenbilding. 1914.
90. ————. The great soil groups of the world and their development. [Trans. by C. F. Marbut]. 1927.
91. Gracanin, M. Die Koncentration der Nährlösung als Faktor des Wurzelwachstums. Lab. Pl. Nutr., Univ. Zagreb. 1935.
92. Graham, Ellis R. Calcium transfer from mineral to plant through colloidal clay. Soil Sci. **51**: 65–69. 1941.
93. Greaves, J. E. and Yeppa Lund. The role of osmotic pressure in the toxicity of soluble salts. Soil Sci. **12**: 163–181. 1921.
94. Greene, H. and O. W. Snow. The effect of irrigation and dry fallow on a heavy, base saturated soil. Third Int. Cong. Soil Sci. Vol. 1: 21–24. 1935.
95. Grim, R. E. Modern concepts of clay materials. Jour. Geol. **50**: 225–275. 1942.
96. Guest, P. L. Root-contact phenomena in relation to iron nutrition and growth of citrus. Proc. Am. Soc. Hort. Sci. **44**: 43–48. 1944.
97. Hansteen, B. Über das Verhalten der Kulturpflanzen zu den Bodensalzen. I, II. Jahr. Wiss. Bot. **47**: 289–376. 1910.
98. Harris, A. E. Effect of replaceable sodium on soil permeability. Soil Sci. **32**: 435–446. 1931.
99. Harris, F. S. Soil alkali. 1920.
99*a*. ————. Effect of alkali salts in soils on the germination and growth of crops. Jour. Agr. Res. **5**: 1–53. 1915.
99*b*. ————. Soil alkali studies. Quantities of alkali salts which prohibit the growth of crops in certain Utah soils. Utah Agr. Exp. Sta., Bul. 145. 1916.
99*c*. ———— and D. W. Pittman. Relative resistance of various crops to alkali. Utah Agr. Exp. Sta., Bul. 168. 1919.
100. Harris, J. A. The relationship between the concentration of the soil solution and the physicochemical properties of the leaf-tissue fluids of Egyptian and Upland cotton. Jour. Agr. Res. **32**: 605–647. 1926.
101. ———— *et al.* The osmotic concentration, specific electrical conductivity, and chloride content of the tissue fluids of the indicator plants of Tooele Valley, Utah. Jour. Agr. Res. **27**: 893–924. 1924.

102. ———— *et al.* The leaf-tissue fluids of Egyptian cottons. Jour. Agr. Res. **31**: 1027–1033. 1925.
103. ———— *et al.* Sulphate content of the leaf-tissue fluids of Egyptian and Upland cotton. Jour. Agr. Res. **31**: 653–661. 1925.
105. ———— *et al.* On the osmotic pressures of the juices of desert plants. Science **41**: 656–658. 1915.
106. ———— *et al.* The cryoscopic constants of expressed vegetable saps as related to local environmental conditions in Arizona deserts. Physiol. Res. **2**: 1–49. 1915.
107. ———— AND T. A. PASCOE. Further studies on the relationship between the concentration of the soil solution and the physicochemical properties of the leaf-tissue fluids of cotton. Jour. Agr. Res. **41**: 767–788. 1930.
108. HARRISON, W. H. Soils and soil conditions. Sci. Reps. Agr. Res. Inst. (Pusa) 1917–18, 27–30.
108*a*. HARTER, L. L. The variability of wheat varieties in resistance to toxic salts. U. S. Dept. Agr., Dept. Bul. 79. 1905.
109. HAYWARD, H. E. AND R. UHVITS. [Unpublished work].
110. ———— AND E. M. LONG. Anatomical and physiological responses of the tomato to varying concentrations of sodium chloride, sodium sulfate, and nutrient solutions. Bot. Gaz. **102**: 437–462. 1941.
111. ———— AND ————. Vegetative responses of the Elberta peach on Lovell and Shalil root stocks to high chloride and sulfate solutions. Am. Soc. Hort. Sci., Proc. **41**: 149–155. 1942.
112. ———— AND ————. Some effects of sodium salts on the growth of the tomato. Pl. Physiol. **18**: 556–569. 1943.
113. ———— AND WINIFRED SPURR. Effect of osmotic concentration of substrate on the entry of water into corn roots. Bot. Gaz. **105**: 152–164. 1943.
114. ———— AND ————. The tolerance of flax to saline conditions, effect of sodium chloride, calcium chloride and sodium sulfate. Jour. Am. Soc. Agron. **36**: 287–300. 1944.
115. HEADEN, W. P. Deterioration in the quality of sugar beets due to nitrates formed in the soil. Col. Agr. Exp. Sta., Bul. 183. 1912.
116. HELLER, V. G. *et al.* Sand culture studies of the use of saline and alkaline waters in greenhouses. Pl. Physiol. **15**: 727–733. 1940.
117. HENCKEL, P. A. AND S. S. KOLOTOVA. On increasing the salt-resistance of plants by pre-sowing treatment. Izv. Akad. Nauk, U.S.S.R. Sci. Biol. 474–483. 1940.
118. HENDRICKS, S. Lattice structure of clay materials and some properties of clay. Jour. Geol. **50**: 276–290. 1942.
119. ————. [Personal communication relative to mineral analysis of saline and alkali soils. 1943.]
120. ———— AND L. T. ALEXANDER. Minerals present in soil colloids. I. Descriptions and methods for identification. Soil Sci. **48**: 257–272. 1939.
121. ———— AND WILLIAM H. FRY. The results of X-ray and microscopical examinations of soil colloids. Soil Sci. **29**: 457–479. 1930.
122. HENDRICKSON, A. H. AND F. J. VEIHMEYER. Irrigation experiments with peaches in California. Cal. Agr. Exp. Sta., Bul. 479. Part I. 1929.
123. ———— AND ————. Irrigation experiments with grapes. Proc. Am. Soc. Hort. Sci. **28**: 151–157. 1931.
124. HESTER, J. B. A study of some salt water flooded soils on the eastern shore of Virginia. Soil Sci. **36**: 427–434. 1933.
124*a*. HICKS, G. H. The germination of seeds as affected by certain chemical fertilizers. U. S. Dept. Agr., Div. Bot., Bul. 24. 1900.
125. HILGARD, E. W. Alkali lands, irrigation and drainage in their mutual relations. Univ. Cal., Col. Agr. Rep., App. VII. 1886.

126. ————. Nature, value, and utilization of alkali lands. Cal. Agr. Exp. Sta., Bul. 128. 1900.
127. ————. Soils. 1906.
128. HISSINK, D. J. Base exchange in soils. Trans. Faraday Soc. **20**: 551–566. 1924–25.
129. ————. Beitrag zur Kenntnis der Adsorptionvorgänge im Boden. Methode zur Bestimmung der austauschfähigen oder adsorptive gebunden Basen im Böden und die Bedeutung dieser Basen für die Prozesse, die sich im Böden abspielen. Int. Mitt. Bodenk. **12**: 81–172. 1922.
130. ————. Method for measuring absorbed bases in soils and the importance of these bases in soil economy. Soil Sci. **15**: 269–276. 1923.
131. ————. Der Sattigungszustand des Bodens. A. Mineralböden (Tonböden). Zeit. Pflanzenernähr. u. Dungung—Teil A. **4**: 137–158. 1925.
132. ————. The relation between the values pH, V and S (humus) of some humus soils. S (humus) and V of these soils with pH = 7. The equivalent weight of the humus substance. Int. Soc. Soil Sci., Proc. Sec. Comm. A. 198–207. 1926.
133. ————. The reclamation of a part of the Zuyder Zee. Trans. Sixth Comm. Int. Soc. Soil Sci., Vol. A: 177–187. 1932.
134. ————. Die Salztonböden und die Alkalitonböden in den Niederlanden. Trans. Second Comm. Int. Soc. Soil Sci. Kjøbenhaven A. 185–189. 1933.
135. ————. Der Basenaustauch im Böden. Third Int. Cong. Soil Sci. Vol. 2: 60–74. 1935.
136. HOAGLAND, D. R. Relation of the concentration and reaction of the nutrient medium to the growth and absorption of the plant. Jour. Agr. Res. **17**: 73–117. 1919.
137. ————. Some aspects of the salt nutrition of higher plants. Bot. Rev. **3**: 307–334. 1937.
138. ————. Salt accumulation in plant cells. Symp. Quant. Biol. **8**: 181–194. 1940.
139. ————. Lectures on the inorganic nutrition of plants. 1944.
140. ———— AND T. C. BROYER. Hydrogen ion effects and the accumulation of salt by barley roots as influenced by metabolism. Am. Jour. Bot. **27**: 173–185. 1940.
141. ———— AND ————. Accumulation of salt and permeability in plant cells. Jour. Gen. Physiol. **25**: 865–880. 1942.
142. ———— AND A. R. DAVIS. The intake and accumulation of electrolytes by plant cells. Protoplasma **4**: 610–626. 1929.
143. ———— AND W. C. SNYDER. Nutrition of strawberry plant under controlled conditions. (a) Effects of deficiencies of boron and certain other elements. (b) Susceptibility of injury from sodium salts. Am. Soc. Hort., Proc. **30**: 288–294. 1933.
144. HORNER, G. M. Relation of the degree of base saturation of a colloidal clay by calcium to the growth, nodulation and composition of soy beans. Missouri Agr. Exp. Sta., Res. Bul. 232. 1936.
145. HUNTER, A. S. *et al.* Calcium potassium ratios for alfalfa. Soil Sci. **55**: 61–72. 1943.
146. ILJIN, V. Über die Austrocknungsfähigkeit des lebenden Protoplasmas der vegetativen Pflanzenzellen. Jahr. Wiss. Bot. **66**: 947–964. 1927.
147. ILJIN, W. S. Der Einfluss des Welkens auf den Ab- und Aufbau der Stärke in der Pflanze. Planta **10**: 170–184. 1930.
148. INGALLS, R. A. AND J. W. SHIVE. Relation of H-ion concentration of tissue fluids to distribution of iron in plants. Pl. Physiol. **6**: 103–125. 1931.

149. Italie, Th. B. van. Cation equilibria in plants in relation to soil. Soil Sci. **46**: 175–186. 1938.
150. Jacobs, M. H. Some aspects of cell permeability to weak electrolytes. Symp. Quant. Biol. **8**: 30–39. 1940.
151. Jenny, H. Kationen und anionen Umtausch an Permutitgrenzflächen. Kolloid Chem. Beihefte **23**: 427–472. 1926.
152. ———— and A. D. Ayers. The influence of the degree of saturation of soil colloids on the nutrient intake by roots. Soil Sci. **48**: 443–459. 1939.
153. ———— and R. Overstreet. Contact effects between plant roots and soil colloids. Proc. Nat. Acad. Sci. **24**: 384–392. 1938.
154. ———— *et al.* Contact depletion of barley roots as revealed by radio active indicators. Soil Sci. **48**: 9–24. 1939.
155. ———— and R. Overstreet. Cation interchange between plant roots and soil colloids. Soil Sci. **47**: 257–272. 1939.
157. ———— and R. F. Reitemeier. Ionic exchange in relation to the stability of colloidal systems. Jour. Physiol. Chem. **39**: 593–604. 1935.
158. Juliano, B. and M. J. Aldama. Morphology of *Oryza sativa* Linnaeus. Phil. Agr. **26**: 1–134. 1937.
159. Kearney, T. H. and F. K. Cameron. Some mutual relations between alkali soils and vegetation. U. S. Dept. Agr., Ann. Rep. 71. 1902.
160. ————. On the excretion of hygroscopic salts in *Frankenia* and *Statice*. Science **19**: 419–420. 1904.
161. ————. The wilting coefficient for plants in alkali soils. U. S. Dept. Agr., Bur. Pl. Ind., Circ. 109. 1913.
162. ———— and L. L. Harter. The comparative tolerance of various plants for the salts common in alkali soils. U. S. Dept. Agr., Bur. Pl. Ind., Bul. 113. 1907.
163. ———— and C. S. Scofield. The choice of crops for saline land. U. S. Dept. Agr., Circ. 404. 1936.
164. Kelley, W. P. A general discussion of the chemical and physical properties of alkali soils. Proc. First Int. Cong. Soil Sci. **4**: 483–489. 1927.
165. ————. The essential nature of alkali soils and methods for their reclamation. Mezogazdasagi Kut. Sigmond special No. pp. 439–457. 1933.
166. ————. The formation, evaluation, reclamation, and the absorbed bases of alkali soils. Jour. Agr. Sci. **24**: 72–92. 1934.
167. ————. The so-called Solonetz soils of California and their relation to alkali soils. Am. Soil Survey Bul. **15**: 45–52. 1934.
168. ————. Modern clay researches in relation to agriculture. Jour. Geol. **50**: 307–319. 1942.
169. ———— and S. Brown. Replaceable bases in soils. Cal. Agr. Exp. Sta., Tech. Bul. 15. 1924.
170. ———— and ————. Base exchange in relation to alkali soils. Soil Sci. **20**: 477–495. 1925.
171. ———— and ————. An unusual alkali soil. Jour. Am. Soc. Agron. **31**: 41–43. 1939.
172. ———— and A. B. Cummins. The formation of sodium carbonate in soils. Cal. Agr. Exp. Sta., Tech. Bul. 3. 1923.
173. ———— and W. H. Dore. The nature of the base-exchange material of Bentonite, soils and zeolite as revealed by chemical investigation and X-ray analysis. Soil Sci. **31**: 25–55. 1931.
174. ———— *et al.* The colloidal constituents of American alkali soils. Soil Sci. **51**: 101–124. 1941.
175. ———— *et al.* The colloidal constituents of California soils. Soil Sci. **48**: 201–255. 1939.

176. ———— and H. Jenny. The relation of crystal structure to base exchange and its bearing on base exchanges in soils. Soil Sci. **41**: 367–382. 1936.
177. ———— and J. B. Page. Criteria for the identification of the constituents of soil colloids. Soil Sci. Soc. Am., Proc. **7**: 175–181. 1942.
178. ———— and C. F. Shaw. The meaning of the term solonetz. Rep. Am. Soil Survey Assoc. **16**: 1–3. 1935.
179. ———— and E. E. Thomas. Reclamation of the Fresno type of black-alkali soils. Cal. Agr. Exp. Sta., Bul. 455. 1928.
180. Kellogg, C. E. Morphology and genesis of the solonetz soils of western North Dakota. Soil Sci. **38**: 483–501. 1934.
181. ————. A glossary of special terms used in the Soils Yearbook. U. S. Dept. Agr., Yearbook, 1938.
182. Kerr, H. W. The identification and composition of the soil alumino silicate active in base exchange and soil acidity. Soil Sci. **26**: 385–398. 1928.
183. Kersting-Munster, F. Die Bedeutung des Kalziums fur die höhere Pflanze. Der Forschungsdienst **5**: 48–57. 1938.
184. Kotzmann, L. G. Effect of increasing sodium saturation on the physical properties of the soil. Mezogazdasagi. Kutatasok **8**: 141–146. 1935; Chem. Abs. **29**: 5969.
185. ————. Zusammenhang zwischen der physikalischen Eigenschaften und der Art der absorbierenden Basen der Bodens. Third Int. Cong. Soil Sci. Vol. 1: 24–26. 1935.
186. Kovda, V. A. and L. Ya. Manaeva. Soil toxicity limits of the Pakhta-Aral State Farm (Golodnaya Steppe) for lucerne and cotton growing. Pedology 4: 80–98. 1939; Chem. Abs. **34**: 7953.
187. Kowda, V. A. Die typen der Alkaliböden (Solontzi). Third Int. Cong. Soil Sci. **3**: 99–102. 1935.
188. Kramer, P. J. Soil moisture as a limiting factor for active absorption and root pressure. Am. Jour. Bot. **28**: 446–451. 1941.
189. Krebig, L. Vorkommen, Eigenschaften und Wirtschaftlicher Wert von Magnesia und Kaliboden in Ungarn. Third Int. Cong. Soil Sci. **1**: 353–357. 1935.
189a. Krebig, L. and K. V. Madar. Studienergebnisse über die Einwirkung von Na-haltige Irrigationswasser auf die Boden-eigenschafter. Congress Int. Tech. Chem. Ind. Agr. Proc. Fifth Congress Holland **I**: 249–253. 1937.
190. Larsen, C. A. Reclamation of saline (alkali) soil in the Yakima Valley, Washington. Wash. Agr. Exp. Sta., Bul. 376. 1939.
191. Lehr, J. J. The importance of sodium for plant nutrition. I. Soil Sci. **52**: 237–244. 1941.
192. ————. The importance of sodium for plant nutrition. III. The equilibrium of cations in the beet. Soil Sci. **53**: 399–411. 1942.
193. Lindner, R. C. and C. P. Harley. Nutrient interrelations in lime-induced chlorosis. Pl. Physiol. **19**: 420–439. 1944.
194. Lipman, C. B. A critique of the hypothesis of the lime-magnesia ratio. Pl. World **19**: 83–105, 119–135. 1916.
195. ———— *et al.* The tolerance of plants for NaCl. Soil Sci. **22**: 303–322. 1926.
196. Loehwing, W. F. Calcium, potassium and iron balance in certain crop plants in relation to their metabolism. Pl. Physiol. **3**: 261–275. 1928.
197. ————. Effect of insolation and soil characteristics on tissue fluid reaction in wheat. Pl. Physiol. **5**: 293–305. 1930.
198. ————. Nutritional factors in plant growth and development. Iowa Acad. Sci. **49**: 61–112. 1942.

199. Long, E. M. The effect of salt additions to the substrate on intake of water and nutrients by roots of approach-grafted tomato plants. Am. Jour. Bot. **30**: 594–601. 1943.
200. Loughridge, R. H. Tolerance of alkali by various cultures. Cal. Agr. Exp. Sta., Bul. 133. 1901.
201. Lundegardh, H. Salt absorption of plants. Nature **145**: 114–115. 1940.
202. MacIntyre, W. H. and J. B. Young. The transient nature of magnesium induced toxicity and its bearing upon lime-magnesia ratio studies. Soil Sci. **15**: 427–471. 1923.
203. Mackie, W. W. Reclamation of white-ash lands affected with alkali at Fresno, California. U. S. Dept. Agr., Bur. Soils, Bul. 42. 1907.
204. ————. Rice in the Imperial Valley. 1943. Publ. by Imp. Rice Growers' Assoc. 1944.
206. Magistad, O. C. The aluminum content of the soil solution and its relation to soil reaction and plant growth. Soil Sci. **20**: 181–225. 1925.
207. ————. Ion and plant relationships in western acid soils. Soil Sci. **51**: 461–471. 1941.
208. ———— and O. N. Allen. Effect of liming on the growth of pigeon peas in Hawaiian soils. Phil. Agr. **21**: 654–664. 1933.
209. ———— *et al.* The effect of salt concentration, kind of salt, and climate on plant growth in sand cultures. Pl. Physiol. **18**: 151–166. 1943.
210. ———— and J. E. Christiansen. Saline soils, their nature and management. U. S. Dept. Agr., Circ. 707. 1944.
211. ———— *et al.* Comparison of base exchange equations based on the law of mass action. Soil Sci. **57**: 371–379. 1944.
212. ———— *et al.* Effect of sodium nitrate on permeability of western soils. Cal. Citrog. **29**: 196–197. 1944.
213. ———— and R. F. Reitemeier. Soil solution concentrations at the wilting point and their correlation with plant growth. Soil Sci. **55**: 351–360. 1943.
214. ———— *et al.* Determination of soluble salts in soils. Soil Sci. **59**: ————. 1945. [In press].
215. Magowan, Florence N. The toxic effect of certain common salts of the soil on plants. Bot. Gaz. **45**: 45–49. 1908.
216. Maliushchitskii, N. K. The correlation between the osmotic pressure of nutrient solution and the development and chemical composition of plants. *In* Dnevn. XII. Siezda Russ. Est. Isp. i Vrach (Moscow), No. 9: 414. 1910. Abs. in Zhur. Opuitn. Agron. (Russ. Jour. Exp. Landw.), Vol. 11, No. 1: 122–124; Exp. Sta. Rec. **25**: 125. [Russian abstract seen but not original].
217. Mann, H. B. Availability of manganese and of iron as affected by applications of calcium and magnesium carbonates to the soil. Soil Sci. **30**: 117–141. 1930.
218. Martin, A. L. The effects of magnesium and calcium on "white tip" of rice. Am. Jour. Bot. **26**: 846–852. 1939.
219. Maximov, N. A. The plant in relation to water. 1929.
220. ————. Plant physiology. 1938.
221. McCall, A. G. Physiological balance of nutrient solutions for plants in sand cultures. Soil Sci. **2**: 207–255. 1916.
222. McGeorge, W. T. The base exchange property of organic matter in soils. Ariz. Agr. Exp. Sta., Tech. Bul. 30. 1930.
223. ————. Organic compounds associated with base exchange reactions in soils. Ariz. Agr. Exp. Sta., Tech. Bul. 31. 1931.
224. ————. Organic base-exchange compounds in soils. Jour. Am. Soc. Agron. **26**: 575–579. 1934.

225. ————. Some aspects of citrus tree decline as revealed by soil and plant studies. Ariz. Agr. Exp. Sta., Tech. Bul. 60. 1936.
226. ————. Studies on soil structure: some physical characteristics of puddled soils. Ariz. Agr. Exp. Sta., Tech. Bul. 67. 1937.
227. ————. Some problems connected with fertilization of alkali soils. Cal. Citrog. **24**: 389, 424. 1939.
228. ————. Studies on plant food availability in alkaline-calcareous soils; seedling tests and soil analyses. Ariz. Agr. Exp. Sta., Tech. Bul. 94. 1942.
229. ———— AND J. F. BREAZEALE. The relation of phosphate availability, soil permeability and carbon dioxide to the fertility of calcareous soils. Ariz. Agr. Exp. Sta., Tech. Bul. 36. 1931.
230. ———— AND ————. New light on alkali soils. Cal. Citrog. **21**: 246–247. 1936.
231. ———— AND ————. Studies on soil structure: effect of puddled soils on plant growth. Ariz. Agr. Exp. Sta., Tech. Bul. 72. 1938.
232. ———— *et al.* Aluminum hydroxide in alkaline soils and it effect upon permeability. Ariz. Agr. Exp. Sta., Tech. Bul. 12. 1926.
233. MEHLICK, A. AND W. E. COLWELL. Influence of nature of soil colloids and degree of base saturation on growth and nutrient uptake by cotton and soybeans. Soil Sci. Soc. Am., Proc. **8**: 179–184. 1943.
234. MEHTA, M. L. The soils of the rice areas of the Gujranwala and Sheikhupura division of the upper Chenab Canal. Punjab Irrig. Res. Inst. Res. Publ. **3**(2). 1937.
235. MERKLE, F. G. AND E. C. DUNKLE. Burning injury from fertilizers on greenhouse and field crops. Penn. Agr. Exp. Sta., Bul. 446. 1943; Exp. Sta. Rec. **90**: 755.
236. ———— AND ————. Soluble salt content of greenhouse soils as a diagnostic aid. Jour. Am. Soc. Agron. **36**: 10–19. 1944.
237. MEYER, B. S. AND D. B. ANDERSON. Plant physiology. 1939.
238. MILLER, E. C. Plant physiology. 1938.
239. MITCHELL, J. The origin, nature and importance of soil organic constituents having base exchange properties. Jour. Am. Soc. Agron. **24**: 256–275. 1932.
240. MIYAKE, K. The influence of salts common in alkali soils upon the growth of the rice plant. Jour. Biol. Chem. **16**: 235–263. 1913.
241. MULLER, J. F. Some observations on base exchange in organic materials. Soil Sci. **35**: 229–237. 1933.
242. MURPHY, H. F. The effect of fertilization on the replaceable bases in the soil. Ok. Acad. Sci., Proc. **15**: 41–43. 1935.
243. NEIDIG, R. E. AND H. P. MAGNUSON. Alkali studies: I. Tolerance of wheat for alkali in Idaho soils. Soil Sci. **18**: 449–467. 1924.
244. NEWTON, J. D. The relation of the salt concentration of the culture solution to transpiration and root respiration. Sci. Agr. **5**: 318–320. 1925.
245. NIGHTINGALE, G. T. The nitrogen nutrition of green plants. Bot. Rev. **3**: 85–174. 1937.
246. ———— *et al.* Effects of calcium deficiency on nitrate absorption and on metabolism in tomato. Pl. Physiol. **6**: 605–630. 1931.
247. ———— AND R. B. FARNHAM. Effects of nutrient concentration on anatomy, metabolism and bud abscission of sweet pea. Bot. Gaz. **97**: 477–517. 1936.
248. NIKIFOROFF, C. C. The solonetz-like soils in southern California. Jour. Am. Soc. Agron. **29**: 781–796. 1937.
249. ODEN, S. The humic acids, studies in their chemistry, physics and soil science. Kolloid Chem. Beihefte **11**: 75–260. 1919.
250. OGASA, T. Effect of alkaline salts on the germination of seeds. I. Effect of NaCl solutions on the germination of soy beans, especially on the influence at high and low temperatures. Rept. Inst. Sci. Res.

Manchukuo **3**: 303–315. 1939; Biol. Abst. **15**: 119, No. 1160. 1941. [Original not seen].

251. Olson, L. C. and R. H. Bray. The determination of the organic base-exchange capacity of soils. Soil Sci. **45**: 483–496. 1938.
252. Orlovskii, N. V. and A. M. Kupstova. The fundamental causes of toxic phenomena with plants on Solonetz. Pedology **9**: 73–90 [English summary]. 1939; Chem. Abs. **35**: 4141.
253. Osterhout, W. J. V. The nature of balanced solutions. Bot. Gaz. **47**: 148. 1909.
254. ————. The permeability of protoplasm to ions and the theory of antagonism. Science **35**: 156–157. 1912.
255. Page, H. J. and W. Williams. The effect of flooding with sea water on the fertility of the soil. Jour. Agr. Sci. **26**: 551–573. 1926.
256. Palmer, A. E. Kind, position and toxicity of alkali salts in certain Alberta irrigated soils and tolerance of crops for these salts. Sci. Agr. **18**: 132–140. 1937.
257. Peech, M. and R. Bradfield. The effect of lime and magnesia on the soil potassium and on the absorption of potassium by plants. Soil Sci. **55**: 37–48. 1943.
258. Pepkowitz, L. P. and J. W. Shive. The importance of oxygen in the nutrient substrate for plants—ion absorption. Soil Sci. **57**: 143–154. 1944.
259. Peterson, J. D. and D. S. Jennings. A study of chemical equilibrium existing between soluble salts and base exchange compounds. Soil Sci. **45**: 277–292. 1938.
260. Phillis, E. and T. G. Mason. Further studies on transport in the cotton plant. Ann. Bot. **3**: 889–899. 1939.
261. Pierre, W. H. Hydrogen ion concentration, aluminum concentration in the soil solution, and percentage base saturation as factors affecting plant growth on acid soils. Soil Sci. **31**: 183–207. 1931.
262. Ponder, E. Symposia on quantitative biology. Vol. 7. 1940.
263. Pozdena, L. Investigations on the dispersing action of the sodium ion upon soil samples. Ztsch. Pflanzenernähr. Dungung u. Bodenk. **36A**: 99–104. 1934.
264. Purdy, A. W. Effects of controlled calcium supply on carrots grown in colloidal clay cultures. Am. Soc. Hort. Sci., Proc. **37**: 799–802. 1939.
265. Puri, A. N. The relation between exchangeable sodium and crop yield in Punjab soils and a new method of characterizing alkali soils. Punjab Irrig. Res. Inst. Res., Publ. **4**: 1–4, No. 5. 1934.
266. ———— and Manohar, Lal. Dispersion and stability of soil colloids in water, Part I. Auto-disintegration. Punjab Irrig. Res. Inst. Res. Publ. **4**(10). 1938.
267. ———— *et al.* Dispersion and stability of soil colloids in water. Part II. Ultra-clay and the efficiency of dispersion methods. Punjab Irrig. Res. Inst. Res. Publ. **4**(11). 1938.
268. ———— *et al.* Soil deterioration in the canal irrigated areas of the Punjab, Part III. Formation and characteristics of soil profiles in alkaline alluvium of the Punjab. Punjab Irrig. Res. Inst. Res. Publ. **4**(9). 1937.
269. Raber, O. L. The antagonistic action of anions. Jour. Gen. Physiol. **2**: 541–544. 1920.
270. Rader, L. F. *et al.* The salt index—a measure of the effect of fertilizers on the concentration of the soil solution. Soil Sci. **55**: 201–218. 1943.
271. Ratner, E. I. The influence of exchangeable sodium in the soil on its properties as a medium for plant growth. Soil Sci. **40**: 459–471. 1935.

272. ————. The influence of exchangeable sodium in soils on the growth of plants and the physical properties of the soil. Khimizatziya Sotzialist. Zemledeliya. **3**: 35–45. 1935; Chem. Abs. **30**: 798.
273. Ravikovitch, S. and N. Bidner. The deterioration of grape vines in saline soils. Emp. Jour. Exp. Agr. **5**: 197–203. 1937.
274. ———— and ————. Effects of soil salinity in the Yezreel Valley. Emp. Jour. Exp. Agr. **8**: 207–214. 1940.
275. Reed, H. S. The value of certain nutritive elements to the plant cell. Ann. Bot. **21**: 501–543. 1907.
276. Reitemeier, R. F. [Unpublished].
277. Richards, L. A. and L. R. Weaver. Fifteen-atmosphere-percentage as related to the permanent wilting percentage. Soil Sci. **56**: 331–339. 1943.
278. ———— and ————. Moisture retention by some irrigated soils as related to soil moisture tension. Jour. Agr. Res. **69**: 215–235. 1944.
279. Rosene, H. F. Control of water transport in local root regions of attached and isolated roots by means of osmotic pressure of the external solution. Am. Jour. Bot. **28**: 402–410. 1941.
280. Rost, C. O. Characteristics of some morphological solonetz soils of Minnesota. Jour. Am. Soc. Agron. **28**: 92–105. 1936.
281. ———— and K. A. Maehl. Some solodized soils of the Red River Valley. Soil Sci. **55**: 301–312. 1943.
282. Rudolfs, W. Effects of salt solutions having definite osmotic concentration values upon absorption by seeds. Soil Sci. **11**: 277–293. 1921.
283. ————. Experiments with common rock salt: I. Effect on asparagus. Soil Sci. **12**: 449–455. 1921.
284. Ruhland, W. Untersuchungen über die Hautdrüsen der Plumbaginaceen. Jahrb. Wiss. Bot. **55**: 409–498. 1915.
285. Russell, M. B. Soil moisture sorption curves for four Iowa soils. Proc. Soil Sci. Soc. Am. **4**: 51–54. 1939.
286. Scheffer, F. and P. Schachtschabel. Chemische Beschaffenheit des Bödens. Sec. 2, Handb. Bodenlehre, Blanck. Vol. II. 1939.
287. Schtscherbak, J. Über die Salzausscheidung durch die Blätter von *Statice Gmeline*. Ber. Deut. Bot. Ges. **28**: 30–34. 1910.
289. Scofield, C. S. The effect of alum on silicate colloids. Jour. Wash. Acad. Sci. **11**: 438. 1921.
290. Scofield, C. S. The movement of water in irrigated soils. Jour. Agr. Res. **27**: 617–693. 1924.
291. ————. The Pecos River Joint Investigations. Nat. Res. Plan. Bd., Rep. participating agencies. Wash., D. C. 1942.
292. Sedletskii, I. D. Colloidally dispersed minerals of the principal soil types. Pedology, 61–72. 1942; Chem. Abs. **38**: 4733. [Original not seen].
293. Sergeev, L. I. Salt resistance of wheats. Compt. Rend. Acad. Sci. U.S.S.R. **1**: 563–570. 1935.
294. Shive, J. W. A study of physiological balance in nutrient media. Physiol. Res. **1**: 327–397. 1915.
295. ————. The effect of salt concentration on the germination of seeds. N. J. Agr. Exp. Sta., 38th Ann. Rep. 455–457. 1917.
296. ————. Significant roles of trace elements in the nutrition of plants. Pl. Physiol. **16**: 435–445. 1941.
297. Sigmond, A. A. J. de. Über die Characterisierung des Bodens auf Grund des salzsäuren Bodenauszuges und des Basenaustauschvermögens. Int. Mitt. Bodenk. **5**: 164. 1915.
298. ————. The alkali soils of Hungary and their reclamation. Soil Sci. **18**: 379–381. 1924.

299. ————. Beziehungen der sogenannten kunstlichen Zeolithe mit dem Basenaustausch und den physikalischen Eigenschaften des Bodens. Actes IV Conf. Intl. Pedologie, Rome Vol. 2: 434–443. 1924.
300. ————. Einige vergleichende Untersuchungen üben die Bestimmung der austauschfähigen Kationen, Sattigungszustand und Aziditătsverhaltnisse im Boden. Trans. Sec. Comm. Int. Soc. Soil Sci., Gröningen A: 55–71. 1926.
301. ————. The classification of alkali and salty soils. Proc. First Int. Cong. Soil Sci. Vol. 1: 330–334. 1927.
302. ————. Hungarian alkali soils and their reclamation. Cal. Agr. Exp. Sta., Spec. Publ. 1927.
303. ————. The reclamation of alkali soils in Hungary. Imp. Bur. Soil Sci. Tech. Comm. 23. 1932.
304. ————. Principles and scheme of a general soil system. Soil Res. **3**: 103–127. 1933.
305. ————. The principles of soil science. 1938.
306. ———— *et al.* The effect of calcium and aluminum salts in alkali soil reclamation. Proc. First Int. Cong. Soil Sci. Vol. 2: 512–517. 1928.
307. Silver, A. H. The possibility of utilizing Reh of Sajji Mitti for the manufacture of commercial alkalies. Agr. Jour. India **12**: 477–480. 1917.
308. Singh, T. M. Toxicity of "alkali" salts. Soil Sci. **6**: 463–477. 1918.
309. Slosson, E. E. Alkali studies IV. Wy. Agr. Exp. Sta., Ann. Rep. pp. 1–29. July, 1899.
310. ———— and B. C. Buffum. Alkali studies II. Wy. Agr. Exp. Sta., Bul. 39. 1898.
311. Smirnov, D. S. Peculiarities in the development of flax under the influence of an increased osmotic pressure of the soil solution. Nauch. Agron. Zhur. **3**: 334–340. 1926; Exp. Sta. Rec. **59**: 418–419.
311*a*. ———— *et al.* Ueber die biochemischen Eigentümlichkeiten des Altarius des Laubblätter. Planta **6**: 687–766. 1928.
312. Smirnov-Loginov, V. I. and E. Efendi-Zade. The role of absorbed magnesium in the Tugai soils of Azerbaidzhan. Izvest. Azerbaidzhan. Filiala Akad. Nauk. U.S.S.R. 85–96. 1939; Chem. Abs. **36**: 1426. [Original not seen].
313. Snyder, R. S. *et al.* Alkali reclamation investigations. Id. Agr. Exp. Sta., Bul. 233. 1940.
314. Sorokin, H. and A. L. Sommer. Changes in the cells and tissues of root tips induced by the absence of calcium. Am. Jour. Bot. **16**: 23–39. 1929.
315. Starr, G. H. The control of chlorosis in cottonwood trees and other plants. Wy. Agr. Exp. Sta., Bul. 252. 1942.
316. Steward, F. C. and C. Preston. Effects of pH and the components of bicarbonate and phosphate buffered solutions on the metabolism of potato discs and their ability to absorb ions. Pl. Physiol. **16**: 481–519. 1941.
317. ———— and ————. The effect of salt concentration upon the metabolism of potato discs and the contrasting effect of potassium and calcium salts which have a common ion. Pl. Physiol. **16**: 85–116. 1941.
318. Stiles, W. On the relation between the concentration of the nutrient solution and the rate of growth of plants in water culture. Ann. Bot. **29**: 89–97. 1915.
319. Stol'gane, A. A. Effect of osmotic pressure in nutrient solution of plant growth. Iz Resul't. Veget. Opytov. Lab. Rabot (Rec. Trav. Lab. Agron.) **9**: 514–550; Exp. Sta. Rec. **35**: 434. 1913. [Original not seen].
320. Sushko, S. Y. The role of absorbed magnesium in the formation of solonetz properties in soils. Khim. Sotsial. Zemled. No. 3: 217–220; Chem. Abs. **27**: 5458. 1933. [Original not seen].

321. Tagawa, T. The relation between the absorption of water by plant roots and the concentration and nature of the surrounding solution. Jap. Jour. Bot. **7**: 33–60. 1934.
322. Tamhane, V. A. Tolerance of crops towrad "Kalar". Ann. Rep. Dept. Agr. Sind. 66–74. 1931–2; Chem. Abs. **28**: 6905. [Original not seen].
323. Taylor, E. Mc. *et al.* Soil deterioration in the canal irrigated areas of the Punjab. Part I. Equilibrium between Ca and Na ions in base exchange reactions. Punjab Irrig. Res. Inst. Res. Pub. **4**: 1–15, No. 7. 1935.
324. Thomas, J. E. An investigation of the problems of salt accumulation on a Mallee soil in the Murray Valley Irrigation Area. Coun. Sci. & Ind. Res., Australia, Bul. 128. 1939.
325. Thorne, D. W. and A. Wallace. Some factors affecting chlorosis of high-lime soils: I. Ferrous and Ferric Iron. Soil Sci. **57**: 299–312. 1944.
326. Tiedjens, V. A. and L. G. Schermerhorn. Available calcium a factor in salt balance for vegetable crops. Soil Sci. **42**: 419–433. 1936.
327. Tottingham, W. E. A quantitative chemical and physiological study of nutrient solutions for plant cultures. Physiol. Res. **1**: 133–245. 1914.
328. Treitz, P. Preliminary report on the alkali-land investigations in the Hungarian Great-Plains in the year 1926. Royal Hungarian Geol. Survey. 1927.
329. Tromp, F. J. and J. B. Osborn. A study of Brak soils in the Transvaal. So. Afr. Jour. Ind. **5**: 206–214. 1922; Exp. Sta. Rec. **48**: 420.
330. Truog, E. *et al.* Fertilizer experiments. Methods of application and effect on germination, early growth, hardiness, root growth, lodging, maturity, quality and yield. Wis. Agr. Exp. Sta., Res. Bul. 65. 1925.
331. Tulaikov, N. M. The plant and the salt of the soil. *In* Zhur. Opuitn. Agron. [Russ. Jour. Exp. Landw.], Vol. 13, No. 1: 27–53. 1912; Chem. Abs. **7**: 1778; Exp. Sta. Rec. **27**: 215.
332. Tulaikov, N. M. The soil solution and its importance in the growth of plants. Soil Sci. **15**: 229–233. 1923.
333. Turner, P. E. The state of unsaturation of the soil in relation to its field behavior and lime requirement. Soil Sci. **30**: 349–381. 1930.
334. Van Eijk, M. Analyse der Wirkung des NaCl auf die Entwicklung, Sukkulenz und Transpiration bei *Salicornia Herbacea*, sowie Untersuchungen über den Einfluss der Salzaufnahme auf die Wurzelatmung bei *Aster Tripolium*. Rec. Trav. Bot. Néerl. **36**: 559–657. 1939.
335. Vanselow, A. P. Equilibria of base exchange reactions of bentonites, permutites, soil colloids and zeolites. Soil Sci. **33**: 95–113. 1932.
336. Veihmeyer, F. J. Some factors affecting the irrigation requirements of deciduous orchards. Hilgardia **2**: 125–287. 1927.
337. ———— and A. H. Hendrickson. Soil moisture conditions in relation to plant growth. Pl. Physiol. **2**: 71–82. 1927.
338. Vikulina, L. A. A study of the physiology of sugar and fodder beets on solonetz soils. Trav. Inst. Recherches Biol. Perm. (U.S.S.R.) **8**, No. 1–2: 1–37 [English summary]. 1938; Chem. Abs. **33**: 7022.
339. Vilensky, D. G. The classification of soils on the basis of analogous series in soil formation. Proc. Int. Soc. Soil Sci. Vol. 1: 224–241. 1924.
340. ————. Some data about alkali soils of Russia. Soil Res. **1**: 50–66. 1928.
341. ————. Saline and alkaline soils of the U.S.S.R. Pochvovedenie **4**: 1930; Chem. Abs. **26**: 1691. [Original not seen].
342. Vine, H. *et al.* Studies of aeration of cacao soils in Trinidad Trop. Agric. (B.W.I.) I, **19**: 175–180. 1942; II, **19**: 215–223. 1942; III, **20**: 13–24. 1943; IV, **20**: 51–56. 1943.

343. Vlamis, J. and A. R. Davis. Germination growth and respiration of rice and barley seedlings at low oxygen pressures. Pl. Physiol. **18**: 685–692. 1943.
344. Volkens, G. Die Kalkdrüsen der Plumbaginaceen. Ber. Deut. Bot. Ges. **2**: 334–342. 1884.
345. Wadleigh, C. H. and A. D. Ayers. Biochemical composition of bean plants as conditioned by soil moisture tension and salt concentration. Pl. Physiol. [In press].
346. ———— and H. G. Gauch. Assimilation in bean plants of nitrogen from saline solutions. Am. Soc. Hort. Sci., Proc. **41**: 360–364. 1942.
347. ———— and ————. The influence of high concentrations of sodium sulfate, sodium chloride, calcium chloride, and magnesium chloride on the growth of guayule in sand cultures. Soil Sci. [In press].
348. ———— *et al.* The relation between the chemical nature of the substrate and the degree of chlorosis in corn. Soil Sci. **43**: 153–176. 1937.
349. Waksman, S. A. and K. R. N. Iyer. Contributions to our knowledge of the chemical nature and origin of humus III. The base exchange capacity of "synthesized humus" (ligno-protein) and of natural humus complexes. Soil Sci. **36**: 57–67. 1933.
350. Wall, R. F. and F. B. Cross. Greenhouse studies of toxicities of Oklahoma salt contaminated waters. Ok. Agr. Exp. Sta., Tech. Bul. T–20. 1943.
351. ———— and E. L. Hartman. Sand culture studies of the effects of various concentrations of added salts upon the composition of tomato plants. Am. Soc. Hort. Sci., Proc. **40**: 460–466. 1942.
352. Wallace, T. Investigations on chlorosis of fruit trees. II. The composition of leaves, bark, and wood of current season's shoots in cases of lime-induced chlorosis. Jour. Pom. & Hort. Sci. **7**: 172–183. 1928.
353. ———— and C. E. T. Mann. Investigations on chlorosis of fruit trees. I. The composition of apple leaves in cases of lime-induced chlorosis. Jour. Pom. & Hort. Sci. **5**: 115–123. 1926.
354. Wann, F. B. Control of chlorosis in American grapes. Utah Agr. Exp. Sta., Bul. 299. 1941.
355. Webb, D. *et al.* The effect of replaceable bases on the physical properties of soils with special reference to the effect of replaceable calcium and sodium on index of friability. Soil Sci. **41**: 13–24. 1936.
356. Webster, J. F. and B. Viswanath. Further studies of alkali soils in Iraq. (Mesopotamia) Dept. Agr. Mem. 5 (1921), 1–46; Exp. Sta. Rec. **47**: 811.
357. Weisz, Lorenz. Der Kationen Umtausch an Permutiten und seine Formulierung. Diss., Budapest. 1932.
358. Wet, J. D. de. The reclamation of brak soils. Farm. So. Africa **9**: 69. 1934.
359. White, L. M. and Wm. H. Ross. Effect of various grades of fertilizers on the salt content of the soil solution. Jour. Agr. Res. **59**: 81–100. 1939.
360. Whitney, J. B., Jr. Effects of the composition of the soil atmosphere on the absorption of water by plants. Ohio State Univ., Abs. Doc. Diss. **38**: 97–103. 1942.
361. Whitney, R. S. and R. Gardner. The effect of carbon dioxide on soil reaction. Soil Sci. **55**: 127–141. 1943.
362. Wursten, J. L. and W. L. Powers. Reclamation of Virgin black alkali soils. Jour. Am. Soc. Agron. **26**: 752–762. 1934.

Cytology and Genetics in Relation to Taxonomy ..	C. L. HUSKINS *McGill University*
Techniques for Aseptic Growth of Plants	L. C. KNORR *Cornell University*
Protoplasmic Connections	L. G. LIVINGSTON *Harvard University*
Endomitosis	A. LORZ *Seton Hall College*
Tropical Fruits and Their Future	S. J. LYNCH *Sub-tropical Experiment Station*
Paleobotanical Taxonomy	H. L. MASON *University of California*
Cell-shape	E. B. MATZKE *Columbia University*
Mineral Nutrition of Plants as Affecting Mineral Nutrition of Animals, Including Man	L. A. MAYNARD and K. BEESON *Cornell University*
Genetics and Cytology of Forage Grasses	W. M. MYERS *Pennsylvania State College*
Recent Advances in the Science and Technique of Seed Analysis	R. H. PORTER *Iowa State College*
Polyploidy	L. F. RANDOLPH *Cornell University*
Distribution and Composition of Paleozoic Floras in North America	C. R. READ *U. S. Geological Survey*
Phylogeny of the Basidiomycetes	D. P. ROGERS *Brown University*
Cell Physiology	G. W. SCARTH *McGill University*
Botanical Contributions to the Study of Coal	J. M. SCHÖPF *Illinois State Geological Survey*
Recent Developments of Taxonomic Agaricology ..	A. H. SMITH *University of Michigan*
History of Arctic and Alpine Floras	C. W. SHARSMITH *University of Minnesota*
Phytogeography of the Temperate West Coast of South America	H. E. STORK *Carleton College* and J. L. MORRISON *University of California*
Taxonomy of North American Fresh-Water Algae	L. H. TIFFANY *Northwestern University*
Nematode Diseases of Plants	A. L. TAYLOR *Bureau of Plant Industry*
Measurement of Soil Moisture	F. J. VEIHMEYER *University of California*
Utilization of Native Plants by the American Indians	P. A. VESTAL *Harvard University*
The St. Lawrence River as a Biological Habitat for Higher Plants	FR. MARIE-VICTORIN *University of Montreal*
Vegetable Seed Treatment	J. C. WALKER *University of Wisconsin*
Modern Views and Facts About Growth Substances	P. W. ZIMMERMAN *Boyce Thompson Institute for Plant Research*

Proposed Future Contents of
THE BOTANICAL REVIEW

Articles received and awaiting publication

Taraxacum kok-saghiz as a Source of Rubber ...	G. KROTKOV *Queens University, Canada*
Cytotaxonomy of Nicotiana	T. H. GOODSPEED *University of California*
Tissue Responses to Physiologically Active Substances	BETTY F. THOMSON *Connecticut College*
Absorption of Water by Plants	PAUL J. KRAMER *Duke University*
The Proper Designation of the Vascular Plants...	THEODOR JUST *University of Notre Dame*
Bacterial Galls	A. J. RIKER *University of Wisconsin*
Control of Fungi in Lumber during Air-Seasoning	A. F. VERRALL *U. S. Department of Agriculture*
Detached Leaf Culture	C. E. YARWOOD *University of California*
Laboratory Testing of Spraying and Dusting Fungicides	J. G. HORSFALL *Connecticut Agriculture Experiment Station*
Root Diseases of Deciduous Fruit Trees	J. S. COOLEY *U. S. Department of Agriculture*
Specialization, Hybridization and Mutation in the Cereal Rusts	T. JOHNSON and MARGARET NEWTON *Dominion Laboratory of Plant Pathology*
Preventing Plant Disease Introduction	W. A. MCCUBBIN *U. S. Bureau of Entomology and Plant Quarantine*

Articles arranged for most recently

Heart Rots in Living Trees	R. W. DAVIDSON *U. S. Bureau of Plant Industry*
Cell Walls	T. KERR *North Carolina State College*

Articles in course of preparation

The Cytology of Fertilization in Angiosperms	L. E. ANDERSON *Duke University*
Development of the Madro-Tertiary Flora	D. I. AXELROD *University of California*
Relation of Wood Anatomy to Taxonomy	I. W. BAILEY *Harvard University*
Rubber Formation in Plants	JAMES BONNER and A. W. GALSTON *California Institute of Technology*
Role of the Endosperm in Seed Development	R. A. BRINK and D. C. COOPER *University of Wisconsin*
Heart Rots in Living Trees	R. W. DAVIDSON *Bureau of Plant Industry*
The Angiosperm Embryo Sac	EMMA L. FISK *University of Wisconsin*
American Agar Industry	H. J. HUMM *Duke Marine Laboratory*
Destructive Foreign Plant Diseases not known to be established in North America	N. REX HUNT *Bureau of Entomology and Plant Quarantine*

(*Continued inside*)